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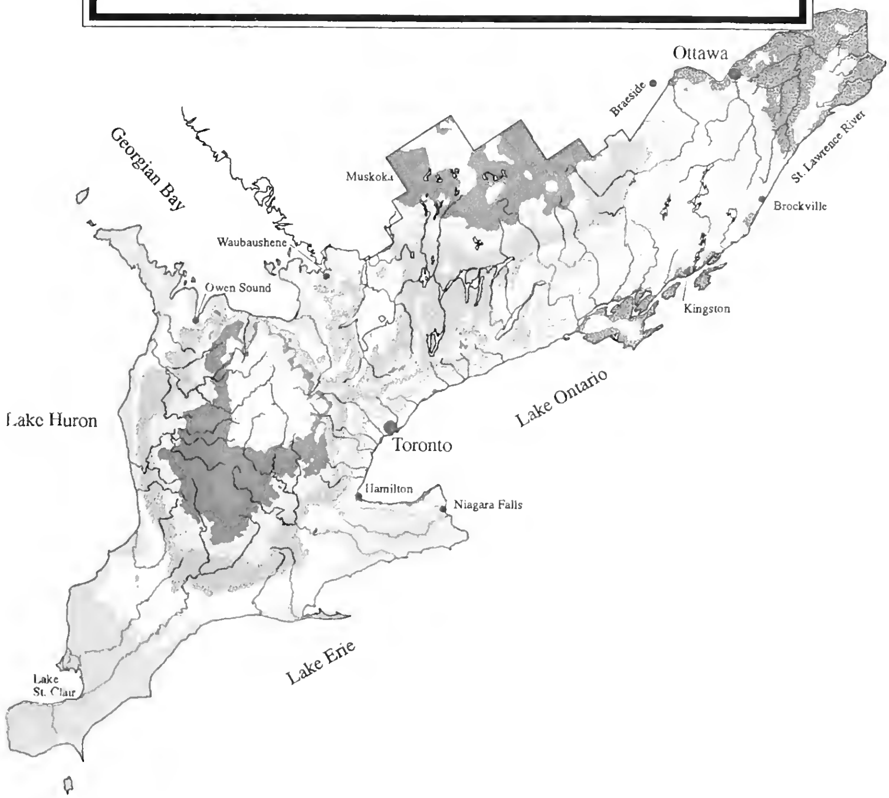
THE HYDROGEOLOGY OF SOUTHERN ONTARIO



Ministry of Environment and Energy

Ontario

Hydrogeology of Ontario
Series (Report 1)

THE HYDROGEOLOGY OF SOUTHERN ONTARIO

VOLUME 1

BY

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PREFACE

This report describes the hydrogeology of southern Ontario in terms of the hydraulic parameters of various bedrock and overburden units, and the geologic conditions under which ground water flow systems operate. In addition, the report provides an assessment of the long-term ground water recharge and discharge, and an evaluation of ground water quality. The report is intended to provide basic hydrogeologic information that can be used for the wise management of the ground water resources in southern Ontario.

Toronto, June 1995

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1. EXECUTIVE SUMMARY

This report describes, on a regional scale, the occurrence, distribution, quantity and quality of ground water in southern Ontario. The report is based mainly on data obtained from the Water Well Information System (WWIS) of the Ontario Ministry of Environment and Energy, and lists almost 100 references representing reports produced over the past 30 years.

Since its inception in 1972, the WWIS database was used by federal, provincial and municipal agencies as well as by academia and consulting firms to conduct hydrogeological investigations related to ground water quantity or quality.

In the past, most of the analysis and interpretation of the information obtained from the WWIS database for a given area was done manually and only a limited number of well records could be considered. Recent advances the area of Geographic Information Systems (GIS) made it feasible to consider large databases, to present the data on thematic maps, and to conduct numerous analyses and interpretations within a relatively short time frame. RAISON is such a GIS system, and is suitable for use with the WWIS database.

Over 215,000 well records were examined in this report. Of these, over 173,000 records that have the highest degree of accuracy in terms of well location and elevation were selected for further analysis. Given that each well record contains up to 212 parameters, the database that was considered is extremely large.

Numerous hydrogeologic techniques were developed by MOEE staff to enhance the RAISON capabilities. These techniques were used to generate for the first time several unique maps of southern Ontario and to conduct numerous hydrogeologic analyses.

Statistical techniques were used to determine the specific capacity and transmissivity distributions for bedrock and overburden wells, and a Streamflow Separation Program was used to assess the long-term ground water discharge and recharge on a monthly and annual basis.

Eighteen hydrogeologic units within the bedrock of southern Ontario were described and their hydraulic parameters were determined. The Bois Blanc, Detroit River Group, Salina, Bass Island, Dundee, and Amabel-Lockport-Guelph hydrogeologic units were identified as the highest water-yielding units within the bedrock of southern Ontario.

Ground water occurrence within various overburden deposits have been described in terms of the hydraulic parameters of wells completed in areas where these deposits outcrop at the surface. Wells completed in areas where deposits of glaciofluvial, glaciolacustrine or marine origins outcrop at the surface show the highest water-yielding capabilities.

The analysis of the ground water level configuration within the bedrock in southern Ontario indicates that it is a subdued reflection of the surface topography where the regional ground water divides coincide closely with the topographic divides of major basins. Ground water appears to flow through river valleys towards the Great Lakes and the Ottawa and St. Lawrence Rivers. The ground water level configuration in the overburden is similar to that in the bedrock, but the patterns are more pronounced.

Data from 33 gauging stations located in small watersheds in southern Ontario were selected for streamflow analysis. Care was taken to ensure that the size of each watershed is less than 200 km^2, that streamflows at all the stations are natural flows, and that the period of record at each station is long enough to allow for the estimation of the long-term means of ground water discharge and recharge.

The streamflow analysis indicates that the long-term means of monthly and annual ground water discharge are highest during the months of March, April and May; they decrease steadily during the period June-October and start to recover during November and December. The long-term means of annual ground water discharge and recharge, calculated for the 33 stations, range from 83.34 to 284.88 mm.

Chemical analyses for 1,055 water samples, collected from wells completed in various bedrock and overburden units, were used to evaluate the natural ground water quality and the types of ground water found in these wells. The quality parameters considered were sodium, total iron, chloride, sulphate, nitrate, hardness, and total dissolved solids.

In general, the natural (raw) ground water quality in southern Ontario was found to be good in terms of sodium, chloride, sulphate and total dissolved solids. In terms of iron and hardness, however, the ground water quality fails at times to meet the Provincial Drinking Water Objectives. In addition, most ground water in southern Ontario is of bicarbonate or calcium-bicarbonate type.

2. INTRODUCTION

2.1 THE SIGNIFICANCE OF ONTARIO'S GROUND WATER RESOURCES

Ground water is a valuable resource, which is of great significance to the public health and economic well-being of all the people of Ontario. It is a major source of water supply for agricultural, commercial, industrial, municipal, and non-municipal public uses; and it is critical for the survival of fish and aquatic life in Ontario's watercourses.

Where available in sufficient quantity, ground water offers substantial advantages over surface water supplies. These advantages include:

- minimum treatment requirements in most cases;
- the avoidance of long, costly pipelines for municipal supplies;
- temperature and water quality are usually uniform; and
- with proper protection, the supply is dependable.

Approximately 475,000 records of water wells constructed after 1945 are on file with MOEE. The total number of wells constructed in the province prior to 1945 is unknown. In recent years, some 12,000 to 20,000 additional wells are reported annually (MOEE, 1994). The construction of water wells has changed considerably as they were first dug with pick and shovel to limited depths. Today, modern drilling equipment allows wells to reach depths of several hundred metres. Similarly, wells and supply systems today are more reliable than their predecessors.

Over one-half of all municipal water supplies in Ontario are from ground water sources. The municipal population dependant on ground water is approximately 1.5 million. In rural settings, an additional 1.3 million people obtain their water supplies from private ground water sources (Singer, 1990). It is estimated that an individual's daily water requirements for domestic purposes range from 270 to 450 l/day (MOE, 1987). Based on these figures, the total domestic ground water use in Ontario is estimated to range from 756,000 to 1,260,000 m^3/day.

Water wells are by far the major source of water supply for farm operations. In Ontario, about 90% of farms make use of ground water for household purposes (30,000-65,000 m^3/day) and about 80% make use of it for livestock watering (210,000 - 240,000 m^3/day) (OMAF, 1985).

Ground water is also an important source of water supply for irrigation purposes. Approximately, 40,250 ha of cropland are being irrigated from surface and ground water sources. Irrigation requires an enormous amount of water (150,000 - 170,000 m^3/day), and it is concentrated in several weeks of the year during critical periods of the growing season (OMAF, 1985).

With consumer trends to eat healthier food, demand for fish in Ontario is continually rising. An aquacultural industry (fish hatcheries) is expanding in the province to meet this increasing consumer demand. While aquacultural operations are usually associated with surface water, ground water is a major source of water supply for many of these operations.

Based on published water well records (1946-1984), about 6,000 wells provide water supplies to service stations, motels, snow making, car washes, arenas, shopping plazas, laundromats, restaurants, and cold storage sheds, to name a few.

Approximately 1,700 wells provide water supplies to milk or food processing plants, industrial cooling, steam boilers, hydrostatic testing of pipelines, mining operations, and gravel and crushed stone washing.

Over 6,000 wells are being used for non-municipal public water supply. Schools, hospitals, churches, public washrooms, campgrounds, picnic grounds, and conservation areas all make use of ground water supplies.

Heat pumps and air conditioning units make use of the nearly constant ground water temperature, and their popularity is on the increase. To date, about 25,000 ground-source heat pump systems have been installed in Ontario and many of these systems are of the open-loop type.

To date, there are no reliable estimates of the amount of ground water use for commercial, industrial, and non-municipal public supplies or for aquacultural operations and open-loop heat pump systems.

One of the most important attributes of ground water, which is often overlooked, is its perennial contribution to surface water throughout the year. Over most of Ontario, the mean annual contribution of ground water to streamflow is less than 20%. However, in areas where sand and gravel deposits outcrop at the surface, ground water contribution to streamflow can be up to 60% of the mean annual streamflow. During low flow periods, up to 100% of the flow in many streams consists of ground water discharge.

Ground water perennial contribution to streamflow is significant for the survival of fish and aquatic life in Ontario watercourse and it is essential for the preservatuion of Ontario's coldwater fisheries. The waste assimilative capacities of many Ontario streams during drought periods is entirely dependant on ground water contribution to streamflow.

2.2 IMPORTANCE OF SCALE IN HYDROGEOLOGIC STUDIES

Hydrogeologic studies can be conducted on site, sub-watershed, watershed or regional scales. The scale of a hydrogeologic study determines the type and amount of data required, the techniques used, the degree of accuracy of the maps produced, and most importantly the cost of the study.

As Struckmeier and Margat (1995) indicate, in thematic cartography the expression small (regional), medium (watershed) or large scale (sub-watershed, site) is arbitrary and depends on the size of the country.

In Ontario, hydrogeologic studies on site scales of 1:5,000 - 1:10,000 are conducted to solve problems in a small local area. Examples include provision of water supplies to new sub-divisions, selection of a landfill site, decommissioning of a contaminated site or extraction of sand and gravel.

The size of the area of interest is measured in a few hectares. The study is usually intensive and the data have to be highly accurate. The study may involve the production of an accurate topographic map, drilling of many wells, detailed analyses of geologic logs, pumping tests, and water quality assessment.

Hydrogeologic studies on a sub-watershed scale (1:10,000 - 1:25,000) usually focus on the specific details that a watershed study does not allow for. The size of the area of interest ranges from 10-100 km^2. The study may involve spot streamflow measurements, construction of cumulative stream discharge graphs, use of piezometers and seepage metres, continuous measurements of limited runoff events, spot temperature measurements, delineation of ground water recharge and discharge boundaries, water level measurements in wells, pumping tests, water mass balance, and ground water modelling.

In a hydrogeologic study on a watershed scale (1:50,000 -1:100,000), the objective is to describe the ground water resources in the watershed. The watershed size usually ranges from 100 to 1500 km^2. The study may include the compilation, analysis and interpretation of existing watershed physical data; the compilation, analysis, and interpretation of geologic information; the identification of major aquifers and their water-yielding capabilities; the quantification of ground water long-term recharge and discharge; a water budget analysis; and the evaluation of ground water quality.

In a hydrogeologic study on a regional scale (1:500,000 - 1:1,000,000), the objective is to provide a general overview of the significant elements of the ground water regime within the area of interest, which is usually over 5,000 km^2 in size. Such studies are intended to provide basic background information that can be used in hydrogeologic studies on site, sub-watershed or watershed scales.

A hydrogeologic study on a regional scale usually provides a general overview of the area's physical information, major geologic units and their water-yielding capabilities, ground water regimes, long-term ground water discharge and recharge, and general ground water quality.

2.3 PURPOSE AND SCOPE OF THE STUDY

The purpose of this report is to assess, on a regional scale, the occurrence, quantity and quality of the ground water resources in southern Ontario. This includes:

- the compilation, analysis and interpretation of existing information related to physiography, geology, topography, drainage and climate;
- the determination of the hydraulic parameters of important hydrogeologic units;
- the identification of the geologic conditions under which various ground water flow systems operate;
- the evaluation of the long-term ground water recharge and discharge for selected watersheds; and
- the assessment of ground water quality.

The maps included in this report are of 1:3,300,000 scale. These maps, however, are accurate to a scale of 1:1,000,000. Enlargement of the maps beyond a scale of 1:1,000,000 will introduce unacceptable errors.

2.4 LOCATION

The area of interest, referred to in this report as southern Ontario, has an area of about 100,000 km^2, a length of about 830 km in a northeast-southwest direction and a width which varies between 40 and 360 km in a northwest-southeast direction.

Southern Ontario extends between longitudes 74° 20' and 83° 7' W and latidudes 41° 54' and 45° 34' N. It is bounded on the north by the counties of Muskoka, Nipissing, and Renfrew as well as by Georgian Bay and the Ottawa River; on the east by the province of Quebec, on the southeast by the St. Lawrence River, Lake Ontario, and Lake Erie; and on the west by the Detroit River, Lake St. Clair, the St. Clair River and Lake Huron. Figure 1 shows the location of the study area relative to other parts of Ontario and Figure 2 shows the counties and regional municipalities included in the study.

2.5 RELEVANT INVESTIGATIONS

Bostock (1970) described the physiography of Canada and identified major physiographic regions in Ontario. Chapman and Putnam (1984), in their classic publication entitled: "The Physiography of Southern Ontario", provided a detailed description of the physiography of southern Ontario and an overview of its glacial geology.

Over the last 100 years, numerous geologists and researchers made valuable contributions to enhance the knowledge and understanding of Ontario's geology. These contributions in the form of bulletins, scientific papers, theses, reports and maps continue to provide invaluable background information to practitioners in the field of applied hydrogeology.

In 1992, the Ontario Geological Survey and the Ministry of Northern Development and Mines published a comprehensive volume entitled the: "Geology of Ontario", consisting of 1,430 pages of text, and 41 sheets of maps and charts. This unique volume (Thurston et al, 1992) presents a synthesis of the massive information and data related to Ontario's geology that have accumulated over the past 100 years.

Chapter 10 of the "Geology of Ontario" describes the Grenville Province and the Proterozoic history of central and southern Ontario; Chapter 20 describes the Palaeozoic and Mesozoic geology of the province using a sequence stratigraphy approach; and Chapter 21 provides the first synthesis of Ontario's Quaternary geology. The information contained in this outstanding publication provided invaluable background information that was used extensively in this study.

Regional Analysis of low flow characteristics for the southwestern and west central regions of southern Ontario was completed in 1990. Similar analysis for the central and southeastern regions of southern Ontario was completed in 1991 (Cumming Cockburn Limited, 1990 and 1991).

2.6 PREVIOUS HYDROGEOLOGIC INVESTIGATIONS

The first preliminary ground water survey in Ontario was conducted by Gwynne in 1945 (Watt, 1952). After this survey was completed, it was realized that any future ground water studies must have accurate drilling records as their basis.

The Well Drillers' Act provided the framework for the water well legislation and the Minister of Mines was given the authority to make the necessary regulations to issue licences to well drillers and request them to submit well records. Currently, the Minister of Environment and Energy has under the Ontario Water Resources Act the supervision of all surface and ground water in the province.

A great body of knowledge related to Ontario's ground water resources has been accumulated since 1945. Watt (1952) provided the first overview of ground water in the province. The overview was based on measurements in observation wells and driller's records.

In 1969, the Ontario Water Resources Commission published its first drainage basin report in its Water Resources Series. This tradition was continued after the incorporation of the Commission within then the Ontario Ministry of the Environment (MOE). Twenty four reports, which provide detailed information on the water resources of various watersheds in Ontario, have been published. The reports contain information on ground water flow systems, bedrock topography, overburden and bedrock geology, and hydrochemistry.

Sibul (1969) described the water resources of the Big Otter Creek basin in terms of water occurrence, distribution, quantity and quality in relation to the existing water uses in the basin. The report contains a hydrologic budget analysis that accounts for changes in ground water storage.

Yakutchik and Lammers (1970) described the water resources of the Big Creek basin. The report provides information about the bedrock and surficial geology of the basin and examines the source, occurrence, movement and recharge of ground water.

Two reports by Barouch were published in 1971. The first report deals with hydrograph separation in the Wilmot Creek basin using recession factor analysis and chemistry of streamflow. The second report provides an evaluation of the ground water storage capacity in the Soper Creek basin using a physical parametric approach.

Sibul and Choo-Ying (1971) described the water resources of the Upper Nottawasaga River basin. The report contains information about the occurrence, distribution, quantity and quality of water in the basin.

Sibul et al (1974) described the water resources of the Moira River basin. The report provides information about the occurrence of ground water in Precambrian, Palaeozoic and overburden aquifers.

Singer (1974) described the hydrogeology along the north shore of Lake Ontario in the Bowmanville-Newcastle area, and provided an estimate of the quantity of ground water flow into Lake Ontario. A paper by Singer (1975) describes the simulation of the dynamic response of ground water to natural stresses in the Wilmot Creek basin. The computer simulation was based on finite difference techniques.

Two reports by Funk were published in 1977. The first report describes the geology and ground water resources of the Wilton Creek basin. The second report describes the geology and water resources of the Bowmanville, Soper and Wilmot Creeks basins. Also, Funk (1979) described the geology and water resources of the East and Middle Oakville Creeks basin.

Coward and Barouch (1978) described the ground water resources in the Blue Springs Creek basin. The authors also described a ground water model, which simulates ground water flow in the basin.

Sibul et al (1978) described the ground water resources of the Duffins Creek-Rouge River basins. The report contains the results of subsurface geologic investigation aimed at locating and defining the major aquifer systems in the basins.

Two reports by Ostry were published in 1979. The first report describes the hydrogeology of the Forty Mile and Oakville Creeks basins. The second report describes the results of a hydrogeologic investigation of an area within the Duffins Creek basin.

Chin et al (1980) provided a brief description of the water resources of the South Nation River basin. The report contains maps, graphs and tables related to the quality and availability of ground water in the basin.

Sibul et al (1980) described the ground water resources in the Grand River basin. The report provides information about water yields of wells completed in various bedrock and overburden aquifers.

Goff and Brown (1981) described the ground water resources of the Thames River basin. The report contains 13 sheets of maps, which show the distribution, quality and availability of ground water in the basin.

Singer (1981) provided an evaluation of the ground water responses in the Bowmanville, Soper, and Wilmot Creeks basin. The report examines in detail the inter-relationships between ground water and other components of the hydrologic cycle.

Vallery et al (1982) provided a summary of the water resources of the Holland and Black Rivers basins. The report contains several sheets of maps related to the availability and quality of ground water within both basin.

Singer et al (1994) provided an evaluation of the ground water resources in the Credit River watershed. The report contains an assessment of the long-term ground water recharge and discharge in the watershed as well as an analysis of ground and surface water quality.

In 1990, the Ontario Government announced a Provincial Expression of Interest in the Oak Ridges moraine in response to increasing development pressures on this environmentally significant landform. As a result, a hydrogeologic study of the moraine was initiated in 1991. A number of federal, provincial and municipal agencies as well as consulting firms and the University of Toronto participated in the study

Between 1973 and 1978, MOE published the Major Aquifers in Ontario Map Series, consisting of eight maps that covered most of central and eastern Ontario. The Series identified major aquifers in terms of their spatial extent and ground water yield potential (Turner, 1976, 1977 and 1978).

The Ground water Probability Map Series was initiated in 1969. Between 1969 and 1986, fourteen maps were published. These maps covered large areas in southwestern and central Ontario and illustrated the potential availability of ground water in these areas.

Between 1981 and 1986, MOE has prepared susceptibility maps for 26 areas in the province. The maps show the relative susceptibility of ground water to contamination in those areas. A high/low rating system was used to prepare the maps. The rating system was based on the presence or absence of shallow aquifers, the permeability of surface materials and ground water use.

Numerous scientists and hydrogeologists, associated with various Ontario universities and consulting firms, have made great contributions that enriched our knowledge regarding the hydrogeology of the province. Through their research and investigations, massive amounts of information and data on ground water conditions in various parts of Ontario have been generated.

2.7 ACKNOWLEDGEMENTS

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3. GEOGRAPHY

3.1 PHYSIOGRAPHY

The physiography of southern Ontario has been shaped by geological processes including plutonism, sedimentation, faulting, glaciation, uplifting, erosion, and weathering. One of the most important processes that profoundly reshaped the surface features of southern Ontario during the Quaternary Period has been glaciation. A variety of glacial landforms such as drumlins, eskers, kames, and moraines contribute to the diversity in relief.

According to Bostock (1970) and Thurston et al (1992), geological and physiographic distinctions can be made between two main physiographic regions of Ontario: the uplifted broad dome of the Canadian Shield and the surrounding flatter lowlands termed the Borderlands. The land lying north of lines drawn from Waubaushene on Georgian Bay to Kingston on Lake Ontario, and from Brockville on the St. Lawrence River to Braeside on the Ottawa River, is called the Laurentian Highlands. (Figure 3).

The Laurentian Highlands are underlain by Precambrian bedrock and are characterized by a rugged profile. The surface elevation of the Laurentian Highlands ranges from 485 to 530 m above sea level (a.s.l.) in the northern parts of Haliburton and Hastings Counties to about 60 m (a.s.l.) in the southeast along the shores of the St. Lawrence River. The Laurentian Highlands act as a topographic divide diverting surface drainage to the Ottawa River, Lake Ontario and Georgian Bay.

To the east of the Laurentian Highlands, a triangular-shaped area enclosed between the Ottawa River to the north and the St. Lawrence River to the southeast form a plain known as the Central St. Lawrence Lowlands physiographic region. The surface elevation of the plain ranges from about 60 to 120 m (a.s.l.).

The area to the west of the Laurentian Highlands is known as the Western St. Lawrence Lowland physiographic region. It ranges in elevation from about 75 to 550 m (a.s.l.).

Transecting both the Laurentian Highlands and the Western St. Lawrence Lowland regions are two ridges of Precambrian bedrock known as the Frontenac Arch and the Algonquin Arch, respectively. Although these arches no longer form major topographic features, the distribution of Phanerozoic sedimentary rocks around the arches indicates that these features had been important topographic elements controlling the deposition of the Phanerozoic sedimentary rocks (Thurston et al, 1992).

The Niagara Escarpment subdivides the Western St. Lawrence physiographic region into two parts: the Ontario Lowland to the east of the Escarpment and the Ontario Upland to the west of it.

The Niagara Escarpment extends from Queenston, where it is a 90-metre bluff, along the south shore of Lake Ontario through Hamilton and northward to Collingwood on Georgian Bay. It owes its form to the differential erosion of Palaeozoic rocks that consist of dense dolomites underlain by softer shales. Differential erosion of these dense and soft rocks has resulted in the formation of steep cliffs rising above the Ontario Lowland to the east.

Within the Ontario Lowland, a great ridge known as the Oak Ridges moraine extends north of Lake Ontario from the Niagara Escarpment in the west to Trenton in the east. The moraine, which is composed mainly of sand and gravel, stands about 300 m (a.s.l.). The steep south-facing slopes of the moraine descends to Lake Ontario; whereas the gentle north-facing slopes of the moraine fall off to the Simcoe and Kawartha Lakes region.

The land surface of the Ontario Upland dips regionally to the west and south away from the Niagara Escarpment towards Lake Huron and Lake Erie. The greatest elevation in this area is in Dufferin and Grey Counties where heights between 520 and 550 m (a.s.l.) are reached.

3.2 DRAINAGE

A drainage basin determines the amount and direction of movement that surface water takes and often the direction of movement that ground water takes. The Ottawa River, The St. Lawrence River, Lake Ontario, the Niagara River, Lake Erie, The Detroit River, Lake St. Clair, the St. Clair River, Lake Huron and Georgian Bay form a continuous water boundary around southern Ontario towards which a myriad of drainage systems flow.

Southern Ontario contains parts of the following six major drainage basins (Figure 4):

- the Ottawa River Basin,
- the St. Lawrence River Basin,
- the Lake Ontario Basin,
- the Lake Erie and Lake St. Clair Basin,
- the Lake Huron Basin, and
- the Georgian Bay Basin.

The main tributaries to the Ottawa River are: the South Nation, Rideau, and Mississippi Rivers. Only the South Nation River is entirely within the Central St. Lawrence Lowland physiographic region. The other two rivers rise and have parts of their courses in the Laurentian Highlands physiographic region.

The Cataraqui and Gananoque are the two main tributaries to the St. Lawrence River. They join the St. Lawrence River at Kingston and Gananoque, respectively. The watersheds of both rivers contain numerous narrow, long lakes.

Most of the rivers that flow into Lake Ontario drain small areas. One notable exception is the Niagara River, which joins Lake Erie to Lake Ontario across the Niagara cuesta. Also, the Trent and Moira Rivers have fairly large drainage basins.

Between Niagara-on-the-Lake and Hamilton, a number of small streams drain parts of the back slopes of the Niagara cuesta, descend through V-shaped gorges, and on reaching the base of the Niagara Escarpment they proceed directly to Lake Ontario. Among the most notable of these streams are the Four Mile, Twelve Mile, Twenty Mile and Red Hill Creeks.

Between Hamilton and the Bay of Quinte, the Lake Ontario Basin is bounded by the Niagara cuesta and the Oak Ridges moraine. All the streams that flow into Lake Ontario in this part of the basin are short in length. Among the most notable of these streams are the Oakville and Etobicoke Creeks; the Humber, Don and Rouge Rivers; Duffins, Oshawa and Bowmanville Creeks; and the Ganaraska River.

A number of large rivers drain into the Bay of Quinte, including the Trent, Moira, and Salmon Rivers. All these rivers have their headwaters within the Canadian Shield.

Lake Erie receives no major rivers except the Detroit and Grand Rivers. The Detroit River connects Lake St. Clair to Lake Erie. The Grand River, on the other hand, has the largest catchment in southwestern Ontario and drains most of the highest portions of the Niagara cuesta. Numerous small streams enter Lake Erie at various points along its 400 km shoreline. The most notable of these streams are the Kettle, Catfish, Big Otter and Big Creeks.

The drainage into Lake St. Clair includes the St. Clair, Sydenham and Thames Rivers. The St. Clair River connects Lake Huron to Lake St. Clair; while the Sydenham River drains most of the clay plains of Lambton County. The Thames River is the second largest river in southwestern Ontario. Its main two branches, the North Thames and the South Thames, originate in Logan Township and west of Tavistock, respectively.

The Sauble, Saugeen, Maitland, Bayfield and Ausable Rivers are the major watercourses draining into Lake Huron. Of all these rivers, the Saugeen has the largest catchment that includes some of the highest lands in southwestern Ontario.

A number of rivers drain into Georgian Bay, including the Severn, Nottawasaga, Beaver and Bighead Rivers. Most of the drainage area of the Severn River is located south of the Canadian Shield. The Severn River drains Lake Couchiching, which in turn drains Lake Simcoe. The Nottawasaga, Beaver and Bighead Rivers rise on the Niagara cuesta and flow to Georgian Bay.

In order to make the St. Lawrence River navigable, a series of canals was constructed. This effort was culminated in the building of the St. Lawrence International Seaway which was opened in 1959.

The Welland Canal was built to facilitate navigation between Lake Erie and Lake Ontario. Also, the Trent-Severn Waterway was built to facilitate navigation between Lake Ontario and Georgian Bay.

3.3 CLIMATE

Geology and climate are two critical factors that determine the hydrologic and hydrogeologic characteristics of an area. Geology governs the suitability of certain geologic deposits to act as aquifers, whereas climate controls the availability of water to replenish these aquifers.

According to Brown et al (1968), southern Ontario has a temperate climate with warm summers, mild winters and reliable precipitation. Climatic conditions, however, differ from one location to another and from one year to another. The local variations are created by topography, the proximity to the Great Lakes and the prevailing wind. The annual variations, on the other hand, depend on the nature and frequency of the weather systems that cross the local area.

Precipitation, mainly in the form of rain and snowfall, is fairly uniformly distributed throughout the year. The mean annual precipitation varies from less than 800 mm to over 1000 mm (Figure 5a). It is heaviest in the lee of Lake Huron and Georgian Bay at elevations between 400 to 450 m (a.s.l.); and is lightest along the eastern shores of the Detroit and St. Clair Rivers as well as below the Niagara Escarpment from Niagara through Hamilton to Toronto.

The mean annual snowfall ranges from less than 100 cm to over 300 cm. Snowfall is lightest along the northern shores of Lake Erie and it is heaviest along the southern shores of Georgian Bay
(Figure 5b).

According to Brown et al (1968), the mean annual frost-free period is longest, about 180 days, on Pelee Island in Lake Erie and shortest, about 90 days, in Algonquin Park. Those areas bordering the Great Lakes have significantly longer frost-free periods than farther inland.

Evapotranspiration is the combined removal of water to the atmosphere through evaporation from inland water bodies, snow and soil surfaces as well as through transpiration by plants. Water removed in this way is not available for streamflow or ground water. The mean annual evapotranspiration varies from less than 500 mm to more than 600 mm (Figure 5c). Most evapotranspiration occurs along the northern shores of Lake Erie, and least evapotranspiration occurs in the northern parts of Durham and Victoria Counties.

Runoff consists of that portion of precipitation that reaches rivers and lakes from surface drainage and ground water. Figure 5d shows the spatial distribution of the mean annual runoff in southern Ontario, expressed as depth of water averaged over the drainage basin area. The mean annual runoff ranges from less than 200 mm to greater than 450 mm. Highest values are observed within the Ontario Upland in Dufferin and Grey Counties. Lowest values are observed in Essex, Kent and Lambton Counties in southwestern Ontario (MNR, 1984)

4. DATA AND METHODS USED IN THE STUDY

4.1 DATA USED IN THE STUDY

This study is based mainly on data obtained from the Water Well Information System (WWIS) of the Ministry of Environment and Energy (MOEE). Base map information such as county boundaries and shorelines were digitized from 1:100,000 maps produced by the Ontario Ministry of Transportation.

Additional information such as surface drainage and highways were obtained from digitized maps produced by the Federal Department of Energy, Mines and Resources. Geologic maps of the bedrock and Quaternary geology of southern Ontario were digitized from 1:1,000,000 maps produced by the Ministry of Northern Development and Mines.

Daily streamflow data for 33 hydrometric gauging stations, being maintained by Environment Canada, were used to determine the long-term ground water discharge and recharge in various watersheds within southern Ontario. In addition, the results of 1,055 chemical analyses for water samples, collected from wells completed in various bedrock and overburden units, were used to determine the types of ground water found in these units.

Appendix I provides details about methods and assumptions that were made during the preparation of maps and graphs.

4.2 THE WATER WELL INFORMATION SYSTEM

The water well regulations requiring well records to be submitted to the Ontario Department of Mines came into force early in 1946. The number of records submitted by well drillers annually increased steadily from less than 500 in 1946 to over 4,000 in 1971. To deal with this increasing number of records, the previous Ontario Water Resources Commission decided to initiate the Water Well Information System (WWIS).

The WWIS is a computerized database that was designed in 1972 to allow for the easy input and retrieval of data describing the characteristics of water wells in Ontario (Mantha, 1988). The WWIS database contains 321,066 well records. Most of the records are for wells constructed between 1946 and 1984.

The well record is a document designed mainly to protect the interest of the well owner should a problem related to poor well construction arise, or should maintenance or repairs become necessary. The record is equally important to MOEE staff in their efforts to regulate the well construction industry, and assess the ground water resources of the province.

The well record contains information on up to 212 parameters including:

- surface elevation;
- location: UTM coordinates, county or district, township, borough, city, town or village, lot, concession, and watershed;
- geology: types of materials encountered during drilling;
- water: depths at which water was found, depth to static level, and the kind of water found in terms of being fresh, salty, sulphurous, or containing iron or gas;
- pumping test and well yield;
- well construction details: casings, screens, plugs, and seals;
- date of well completion; and

- names and addresses of well owner and well driller.

The WWIS database also includes a quality control feature, which assigns to the well coordinates and elevations different quality indices. These indices range from 1 for high quality data to 9 for poor quality data. This feature allows the user to select only those data that have the highest degree of accuracy in terms of well location and elevation.

The WWIS database has proven to be an indispensable tool for the mapping and protection of Ontario's ground water resources. Since its inception, no hydrogeologic investigation has been conducted in Ontario without strong reliance on it. The WWIS database will continue to provide valuable information on the occurrence, quantity and quality of ground water to home owners, well contractors, hydrogeologic consultants, academia and various government agencies.

4.3 THE RAISON GIS SYSTEM

In the past, the analysis and interpretation of information obtained from the WWIS database for a given area was done manually. This was a time consuming process because of the great number of records that had to be considered.

Recent advances in the area of Geographic Information Systems (GIS) made it feasible to consider a large amount of data, to present these data on thematic maps, and to conduct numerous analyses and interpretations within a short time frame. The Regional Analysis By Intelligent Systems On A Microcomputer (RAISON) is such a GIS system, and is suitable for use with the WWIS database.

RAISON is a data analysis tool, which was designed for use on personal computers. It was developed as a joint research project by the National Water Research Institute and the University of Guelph, Ontario.

RAISON integrates databases, spreadsheets and GIS capabilities that are particularly suitable for applications involving point data. It provides an environment for displaying the data and analytical results in the context of local geography. In addition, enhanced statistical techniques are included in RAISON and advanced modelling can be performed.

The "RAISON Database" is a subsystem within RAISON that allows the user to maintain files through the use of "Delete Record" and "Edit Record" functions. Data may be exported in dBASE or Lotus 123 formats for use in programs external to RAISON, or for exchange with other users using similar data formats. In addition, data may be imported into RAISON as ASCII files from the mainframe computer or from other software packages.

Normally, data are either entered manually into RAISON or an existing database is retrieved. Using the RAISON Database subsystem, links and basic analyses may be done. Relevant results may then be transferred into a spreadsheet and further analyses can be performed.

The results obtained from various RAISON analyses may be displayed graphically in the form of charts, graphs, maps or cross-sections. As is the case with other GIS systems, RAISON may display the results in colours or symbols so that similar regions may be readily identified. This RAISON capability has been extremely useful in conducting the hydrogeologic analyses presented in this report.

Using the mainframe FOCUS software, the water well records for the study area were down loaded from the mainframe computer into a PC. The records were then converted from ASCII type files into dBASE type files. Data were organized in such a way that they can be accessed by the RAISON Database subsystem, retrieved into the RAISON spreadsheet for analysis, or displayed using the RAISON GIS subsystem.

A number of hydrogeologic, analytical techniques were developed by MOEE staff specifically for the interpretation of the WWIS database in conjunction with RAISON. These techniques allow the user to produce various maps and geologic cross-sections, to convert the specific capacity data to transmissivity estimates, and to perform streamflow separation.

The following types of maps and graphs, all of which are contained in this report, have been produced:

- well location,
- well type (bedrock or overburden),
- kind of ground water in the bedrock,
- kind of water in the overburden,
- bedrock topography,
- overburden thickness,
- ground water level elevation in the bedrock,
- ground water level elevation in the overburden,
- specific capacity of bedrock wells,
- specific capacity of overburden wells,
- transmissivity of bedrock wells, and
- transmissivity of overburden wells.

5. HYDROGEOLOGIC DEFINITIONS

5.1 GROUND WATER

Subsurface waters occur in two zones below the land surface: the unsaturated vadose zone and the saturated zone. The first zone extends from the land surface down to the water table and includes the capillary fringe. This zone contains liquid water under less than atmospheric pressure, and water vapour and air or other gases at atmospheric pressure. In parts of this zone, interstices, particularly the small ones, may be temporarily or permanently filled with water. The second zone (i.e. the saturated zone) is that zone in which all voids, large and small, are filled with water under pressure greater than atmospheric (Lohman, 1972). The top boundary of the saturated zone, at which pressure is atmospheric, is called the water table.

Ground water is that part of the subsurface water, which occurs in the zone of saturation and is subject to continuous movement. The geometry and intensity of ground water flow are dependent on the hydrologic environment, consisting of topography, climate and geology (To'th, 1972). The source of, and recharge to ground water comes from precipitation, directly by infiltration from the land surface or indirectly by surface water leaking from streams, ditches or ponds.

The land surface topography exerts a controlling influence upon the configuration of the water table, the distribution of flow systems and, consequently, ground water movement. The occurrence, movement, quality and availability of ground water also depend on geologic factors such as lithology, porosity, permeability and the spatial distribution of various deposits.

5.2 AQUIFERS

An aquifer is a geologic deposit capable of storing and transmitting a large quantity of water. Aquifers vary in thickness and areal extent. Some aquifers are small and may only be able to supply water to one or a few households. Others are large ranging in size from a few hectares to hundreds of square kilometres.

Aquifers may be found in the bedrock or in the overburden (unconsolidated materials) overlying the bedrock. The more fractures and openings there are in the bedrock the higher is the water yield of the aquifer. In the overburden, aquifers consist of sand and/or gravel. Coarse sands and gravels constitute good aquifers, while fine sands and silts are indicative of poor aquifers.

The best bedrock aquifer in southern Ontario, which provides high quality water, is the Amabel-Lockport-Guelph aquifer complex. The largest overburden aquifers, on the other hand, are the Oak Ridges aquifer complex located north of Lake Ontario and the Alliston aquifer complex located south of Georgian Bay.

A geologic deposit that is saturated with water but has low permeability and, therefore, does not furnish an adequate supply of water is called an aquiclude. Examples of aquicludes are clay deposits or poorly-fractured rock formations with a few interconnected pore spaces.

An aquifer that is overlain by a confining layer that has low permeability is called an artesian or a confined aquifer. Ground water in wells drilled in confined aquifers rises above the point where the water is found and may flows over the ground surface.

5.3 HYDRAULIC PARAMETERS

Ground water occurs in the openings within the aquifer. These openings may be in the form of pore spaces between the grains of silt, sand or gravel, or in the form of solution cavities, fissures, joints and bedding planes. The ratio of the volume of the pore spaces to the total volume of the water-bearing material is called porosity.

In unconsolidated deposits, porosity is controlled by the shape, arrangement, degree of sorting and cementation of particles. Porosity is high in well sorted deposits and low in poorly sorted and highly cemented deposits. In consolidated rocks, porosity is dependent on the extent of cementation and the degree of development of the fissure system or the solution cavity openings. Effective porosity refers to the amount of interconnected pore spaces or other openings available for water transmission.

Porosity is not a measure of the amount of water that an aquifer will ultimately yield. The ratio of the volume of water that the rock, after being saturated, will yield by gravity to the total volume of the rock is called the specific yield. The specific retention is the complement of the specific yield. It is the ratio of the volume of the water that the rock, after being saturated, will retain against the force of gravity to the total volume of the rock.

The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an unconfined aquifer, the storage coefficient is virtually equal to the specific yield. However, in a confined aquifer, it is less than the specific yield as the water derived from storage comes from expansion of the water and compression of the aquifer. Similarly, water added to storage is accommodated by compression of the water and expansion of the aquifer (Lohman, 1972).

Ground water flow occurs under a hydraulic gradient which is defined as the change in static head per unit of distance along the ground water flow path. The relative ease with which a water- bearing material can transmit water under a hydraulic gradient is a measure of the permeability or hydraulic conductivity of the material, and is a measure of the capacity of the material to transmit water.

Transmissivity is the rate at which water, at the prevailing kinematic viscosity, is transmitted through a unit width of the aquifer under a unit hydraulic gradient, and is equal to the product of the hydraulic conductivity of the aquifer and its thickness.

The specific capacity of a well is defined as its yield per unit of drawdown, expressed as litres per minute per metre of drawdown (l/min/m). Dividing the yield of a well by the drawdown for a specific time during a pump test, gives the value of specific capacity.

The specific capacity of a well is a function of the type of the aquifer, well diameter, pumping time, partial penetration, hydrogeologic boundaries and well construction characteristics. Because of the above-mentioned constraints, the specific capacity is not an exact criterion with which to calculate the transmissivity. It is, however, a useful index to describe the water-yielding characteristics of the well and of the formation the well taps. In general, high specific capacities are indicative of high transmissivities and, consequently, high water-yielding capabilities.

In applied hydrogeology, pumping and recovery tests of wells generally give the most reliable results for determination of the hydraulic constants of materials surrounding a well. Often, however, the only available data for the wells are the final drawdowns associated with pumping tests of short durations. These data can be used to calculate the specific capacity distribution for the wells and to describe the water-yielding characteristics of the formation(s) the wells tap.

The hydraulic properties of an aquifer are expressed quantitatively by the hydraulic conductivity, and by the coefficients of transmissivity and storage. These properties can be estimated using pumping test data.

There are a number of methods to calculate the aquifer constants from pumping test data. The most widely used methods are based on:

- measurement of drawdown in an observation well during pumping,
- measurement of drawdown of the pumped well during recovery, and
- drawdown-distance method, using the drawdowns in the observation and pumped wells at the end of the pumping period.

Unfortunately, only a few data on pumping tests are available for wells in the study area and most of these data are incomplete. On the other hand, thousands of specific capacity values, based on short-duration pumping tests, are available. These data were used to supplement the data on pumping tests.

Theis et al (1963) described a method for estimating the transmissivity of an aquifer from the specific capacity of a well. The method is based on the Jacob Equation, given in consistent units as:

$$T = (Q/12.6 * s) \ln [(2.25\ T * t)/(r^2 * S)] \qquad (1)$$

where

T = transmissivity (L^2/t),
Q = discharge (L^3/t),
s = drawdown in the well (L),
t = pumping time (t),
S = storage coefficient (dimensionless), and
r = radius of the well (L).

Because T appears twice, equation (1) cannot be solved directly. Graphical solutions involving matching the specific capacity data to a family of curves were proposed. These solutions, however, have the disadvantage of requiring a different set of curves for every possible combination of well radius, pumping period and storage coefficient. In addition, any corrections for partial penetration or well loss require additional calculations.

A computer program, which uses an iterative technique, corrects for partial penetration and well loss, and provides a rapid estimate of transmissivities at hundreds of data points, was developed by Bradbury and Rothschild (1985). The program was modified to accept the format of the WWIS data, and was linked to the RAISON System to allow for the use of RAISON's contour mapping routines and statistical programs. Using the above computer program, the transmissivity values for wells completed in various hydrogeologic units were determined.

To determine the statistical distribution, mean and range of the specific capacities and transmissivity values, a statistical analysis was applied. For example, in the case of transmissivity, the values for each unit were listed in ascending order of magnitude and assigned probabilities according to the relationship:

$$F = (100 * m)/(n + 1) \qquad (2)$$

where

F = percentage of wells where transmissivities are less than the transmissivity of well of serial number m,
m = serial number of well arranged in ascending order of transmissivity, and
n = total number of wells.

The transmissivity values for various units were then plotted against the percentage of wells on logarithmic probability paper. The transmissivity values for most hydrogeologic units plot approximately as straight lines, indicating that the samples have lognormal frequency distributions. Therefore, it could be concluded that the most

probable transmissivity value for a given hydrogeologic unit is equal to the geometric mean of its individual transmissivity values.

The 10 and 90 percentile values are the transmissivities not exceeded by 10% and 90% of the wells, respectively. They provide a measure of the dispersion of the transmissivity values; a large difference between the 10 and 90 percentiles indicates a large spread and a high standard deviation.

Similar analyses were conducted using the specific capacity data for various hydrogeologic units. The results of these analyses are reported as part of the description of each unit.

6. GROUND WATER OCCURRENCE IN THE BEDROCK

The occurrence, flow and quality of ground water are strongly influenced by geology. Therefore, it is important in any ground water investigation to have a full consideration of the characteristics of the geologic deposits within the area under study.

The bedrock in southern Ontario is a major source of water supplies to agricultural, commercial and industrial operations as well as to municipalities and private home owners. This is specifically true in areas where the overburden is absent or where the thickness of the overburden is small.

Figure 6 shows the locations of wells completed in the bedrock. The figure indicates that most of these wells are located in eastern Ontario, to the north of the Oak Ridges moraine, and above the Niagara Escarpment.

In this study, the records of 133,609 water wells, completed in various bedrock units, were examined. Information related to the quality of ground water, encountered in various bedrock units, is available for 129,797 wells. Table 1 gives the total number of bedrock wells by county and summarizes the data related to the kind of water found in bedrock wells in terms of being fresh, salty, mineral, sulphurous or containing gas.

A total of 69,649 records, which have the highest degree of accuracy in terms of well location and elevation, were selected to determine the specific capacity and transmissivity distributions for various hydrogeologic units within the bedrock of southern Ontario.

6.1 BEDROCK TOPOGRAPHY

The bedrock in most of central and southwestern Ontario is obscured by a thick mantle of overburden deposits. The bedrock, however, outcrops at surface over large areas in central and eastern Ontario.

Precambrian rocks of the Canadian Shield outcrop at surface over most of the Laurentian Highlands physiographic region. Thin Quaternary deposits obscure the Precambrian rocks only at a few places.

It is possible to identify three bands where Palaeozoic rocks outcrop at surface. One band flanks the eastern rim of the Canadian Shield, extending from the Ottawa River in the north to the St. Lawrence River in the south. The second band runs along the southwestern slopes of the Canadian Shield, extending from Addington and Prince Edward Counties in the southeast to Lake Simcoe in the northwest. A third band extends along the northern shores of Lake Ontario from Mississauga to Burlington. Palaeozoic rocks also outcrop at many locations along the Niagara Escarpment and in Bruce County.

Figure 7 is a map of bedrock elevation in southern Ontario. Hatched areas on the figure are those areas where the bedrock is at surface. The figure indicates that the general topography of the bedrock, in areas where it is currently obscured by a mantle of overburden deposits, is very similar to present-day topography.

The elevation of the bedrock within the Canadian Shield decreases radially from 485 to 530 m (a.s.l.) in the north within Haliburton and Hastings Counties to 40 to 80 m (a.s.l.) in the south along the shores of Lake Ontario. Within the Oak Ridges moraine, the elevation of the bedrock ranges from 160 to 200 m (a.s.l.). Bedrock elevations of 40 to 80 m (a.s.l.) are observed in most of the Central St. Lawrence Lowland physiographic region in eastern Ontario (see Section on Physiography).

6.1.1 Dundalk Dome

Above the Niagara Escarpment, a dome-like bedrock structure dominates the topography of the area. The highest parts of the structure are located in Dufferin and Grey Counties where they reach over 480 m (a.s.l.) in elevation. This part of the structure will be referred to in this report as the Dundalk Dome.

During preglacial time, the Dundalk Dome controlled the drainage patterns in southwestern Ontario and diverted surface runoff radially to the east, south, west and north. A major topographic divide, which ran in a south-westerly direction, can be traced from the Dundalk Dome to Essex County. A second topographic divide, ran parallel to the Niagara Escarpment, extending from Collingwood on Nottawasaga Bay to Burlington on Lake Ontario. A third topographic divide ran from the Dundalk Dome through the Bruce Peninsula. A forth divide ran from the Niagara River through the Niagara Peninsula and continued through the Counties of Haldimand, Brant, Oxford and Perth.

6.1.2 Bedrock Valleys

A wide bedrock valley, known as the Laurentian Valley, extends to the east of the Niagara Escarpment from Georgian Bay to Lake Ontario (Eyles et al, 1983). Numerous small bedrock valleys drained the eastern parts of the Dundalk Dome into this wide valley. Also, numerous small bedrock valleys drained an area, currently occupied by the Oak Ridges moraine, either into this wide valley or into the Lake Ontario basin.

A large bedrock valley, parts of which are currently occupied by the Grand River system, drained the southern slopes of the Dundalk Dome. The valley can be traced to the western tip of Lake Ontario. The first reference to this valley was made by Karrow (1973) who named it the Dundas Valley. Another large bedrock valley, which overlapped parts of the current Saugeen River system, drained the western slopes of the Dundalk Dome.

6.2 PRECAMBRIAN ROCKS

The oldest rocks (approximately 1.1 billion years) in southern Ontario are the Precambrian rocks of the Canadian Shield. These rocks form a basement on which all younger deposits rest. As indicated earlier, Precambrian rocks occur at or close to the surface within the Laurentian Highlands physiographic region. The surrounding Borderlands to the east and southwest of the Laurentian Highlands are underlain by younger, sedimentary rocks of the Palaeozoic era.

Precambrian rocks in southern Ontario are considered part of the Grenville Province, which has been subdivided, from north to south, into the Grenville Front Tectonic Zone, the Central Gneiss Belt, and the Central Metasedimentary Belt. Easton (1992) provided a comprehensive description of the Grenville Province based on the latest available information, and compiled an extensive list of references related to Precambrian geology.

According to Easton (1992), the Grenville Front Tectonic Zone extends from north to south through Georgian Bay, Lake Huron, Lake St. Clair, and Essex County. It consists of deformed and metamorphosed rocks.

The Central Gneiss Belt extends from the Ottawa River in the northeast to Lake Erie in the southwest. The belt consists mainly of amphibolite and granulite facies as well as gneisses (Easton, 1992).

The Central Metasedimentary Belt is found throughout the remaining parts of southern Ontario and outcrops at or close to the surface within the Laurentian Highlands physiographic region. The unit is comprised of plutonic and metasedimentary rocks resulting from the extreme metamorphism of older rocks of igneous origin. Plutonic rock types found within the unit include granite, gneiss, granodiorite, diorite, syenite, pegmatite, and gabbro.

Metasedimentary rock types include marble, conglomerate, breccia, arkose, and metamorphosed limestone and siltstone (Easton, 1992).

6.2.1 Precambrian Hydrogeologic Unit

From a hydrogeologic point of view, those Precambrian rocks that are at or close to surface are significant as a source of ground water supplies. The remaining Precambrian rocks are buried under thick sequences of younger rocks and are not tapped for ground water.

According to Sibul et al (1974), approximately, 85% of 400 wells drilled in Precambrian rocks within the Moira River basin obtain suitable water supplies within 15 m of the ground surface. Five percent of the wells have failed to supply sufficient water for domestic use and 40% yield less than 10.00 l/min. Yields in excess of 2,000.00 l/min, however, have been reported for municipal wells at Deloro, Madoc, and Tweed.

Sibul et al (1974) indicated that ground water yield from Precambrian rocks is a function of the number and size of fractures and joints encountered by a well. Because these openings can begin and end abruptly and because they possess strong directional orientations, well yields in Precambrian rocks are highly variable.

Ostry and Singer (1981) reported on the hydraulic conductivity of 179 wells completed in Precambrian rocks within the Thousand Islands area. The hydraulic conductivity values range from 10^{-5} to 1.34 m/day with a mean of 0.08 m/day.

In this report, a total of 12,381 wells were identified in areas where the Precambrian hydrogeologic unit outcrops at surface. Of these, a sample of 7,875 wells was selected to determine the specific capacity and transmissivity distributions for the wells within the unit. Figure 8 shows the locations of the wells and the ranges of their specific capacities.

An examination of the specific capacity data indicates that 5,158 wells in the sample have specific capacity values less than 5.00 litres per minute per metre of drawdown (l/min/m). A fair number of wells (2,274), however, show good specific capacity values ranging from 5.00 to 50.00 l/min/m; while a minority of wells (50) have specific capacity values higher than 50.00 l/min/m.

The transmissivity distribution for the wells in the sample was derived from the specific capacity data. Figure A1 (Appendix II) shows a transmissivity-probability graph for wells completed in the Precambrian hydrogeologic unit. The transmissivity values plot approximately as a straight line, indicating that the sample has lognormal distribution. The 10 and 90 percentile values are 0.40 and 42.50 m^2/day, and the geometric mean of the sample's transmissivity distribution is 4.20 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Precambrian hydrogeologic unit. The low value of the distribution's geometric mean suggests that the unit has a poor water-yielding capability.

6.3 PALAEOZOIC ROCKS

The Palaeozoic rocks in southern Ontario are principally shales, limestones, dolomites and sandstones. In the central and southwestern parts of southern Ontario, the rocks appear to be flat lying but dip gently to the south or west. In the eastern parts of southern Ontario, however, the relations among the rock formations have been made complex through considerable faulting. Johnson et al (1992) provided a comprehensive description of the Palaeozoic

geology of Ontario using a sequence stratigraphy approach, and compiled an extensive list of references related to Palaeozoic geology.

A large number of Palaeozoic groups, formations, and members of Cambrian, Ordovician, Silurian, and Devonian age have been identified in southern Ontario. From a hydrogeologic point of view, many Palaeozoic units are of limited significance as a source of ground water either because of their finite spatial extent or because they are buried under thick sequences of younger rocks.

In the following sections, an attempt has been made to describe the Palaeozoic units within southern Ontario, and highlight the hydrogeologic characteristics of selected units. The geologic descriptions of the various units are based on Johnson et al (1992), and will be given according to geographic location and in order of oldest to youngest unit.

6.3.1 Early Cambrian Strata

The Covey Hill Formation has been identified in eastern Ontario as being of Early Cambrian age. The unit has a limited spatial extent and consists of conglomerates and sandstones with a maximum thickness of 13 m. Due to its limited spatial extent, the formation is of little hydrogeologic significance.

6.3.2 Upper Cambrian and Lower Ordovician Strata

The Nepean Formation of the Potsdam Group has been identified in eastern Ontario as being of Upper Cambrian age. It consists of sandstones with conglomerate interbeds, and has a thickness of up to 300 m.

Three formations that appear to correlate with the Nepean Formation have been identified in the subsurface in southwestern Ontario east of Longitude 81°W. These units include the Potsdam Formation (conglomerates and sandstones up to 46 m thick), the Theresa Formation (sandstones and sandy dolostones up to 107 m thick) and the Little Falls Formation (dolostones up to 31 m thick).

West of Longitude 81°W, three additional units that also appear to correlate with the Nepean Formation were identified in the subsurface. These units are: the Mount Simon Formation (sandstones up to 50 m thick), the Eau Claire Formation (dolomitic sandstones up to 80 m thick) and the Trempealeau Formation (dolostones up to 75 m thick).

The March and Oxford Formations of the Beekmantown Group have been identified in eastern Ontario as being of Lower Ordovician age. The March Formation consists of sandstones, dolomitic sandstones, sandy dolostones and dolostones. It ranges in thickness from 6 to 64 m. The Oxford Formation consists of dolostones with a maximum thickness of 200 m.

6.3.2.1 The Nepean-March-Oxford Hydrogeologic Unit

No data are available to describe the occurrence of ground water in the Potsdam, Theresa, Little Falls, Mount Simon, Eau Claire or the Trempealeau Formations. Given that these units are overlain by thick sequences of younger rocks, it may be possible to conclude that they are of limited hydrogeologic significance.

Due to their similar lithological composition, the Nepean, March and Oxford Formations were treated in this report as one hydrogeologic unit. Figure 9 shows the spatial distributions of various bedrock hydrogeologic units in eastern Ontario.

A total of 17,642 wells have been identified within the unit. Of these, a sample of 7,418 wells was selected to determine the specific capacity and transmissivity distributions for the wells within the unit. Figure 10 shows the locations of the wells and the ranges of their specific capacity values.

An examination of the specific capacity data indicates that 339 wells in the sample have values less than 1.00 l/min/m, 1,884 wells have values between 1.00 and 5.00 l/min/m, 1,466 wells have values between 5.00 and 10.00 l/min/m, 3,025 wells have values between 10.00 and 50.00 l/min/m, and 697 wells have values greater than 50.00 l/min/m.

The transmissivity values for the wells in the sample were derived from the specific capacity data. Figure A2 (Appendix II) is a transmissivity-probability graph for these wells, which plots as approximately a straight line. The 10 and 90 percentile values are 0.45 and 120.51 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 20.04 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Nepean-March-Oxford hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a good water-yielding capability.

6.3.3 Middle to Late Ordovician Strata in Eastern and Central Ontario

Middle to Late Ordovician deposits occur over a large area in south-central and southeastern Ontario, extending from the Ottawa River to Georgian Bay. The major types of rocks are limestones, dolostones, sandstones and shales.

The Rockcliffe Formation (Middle ordovician) has been identified in a number of small areas in eastern Ontario. It consists mainly of sandstones and shales and has a thickness up to 125 m.

The Shadow Lake Formation is present in eastern, south-central, and southwestern Ontario. The thickness of the formation is generally 2 to 3 m and the maximum thickness is 15 m. In eastern Ontario, the formation consists of dolostones with interbeds of calcareous sandstones. In south-central and southwestern Ontario, the formation consists of dolomitic or calcareous sandstones and mudstones.

Overlying the Shadow Lake Formation is a series of limestones and shales, which comprise the Gull River, Bobcaygeon, Verulam and Lindsay Formations. These units form the Simcoe Group in south-central Ontario, and along with the Shadow Lake Formation they comprise the Ottawa Group in eastern Ontario. In southwestern Ontario, the Middle Ordovician rocks consist of the Black River and Trenton Groups.

The Gull River Formation, with a thickness range of 7.5 to 136 m, is divided into a lower member and an upper member. The lower member consists of limestones and silty dolostones, whereas the upper member consists of limestones.

The Bobcaygeon Formation consists of 7 to 87 m of limestones with some shales. The Verulam Formation consists of limestones with interbeds of shales. The unit has a thickness range of 32 to 65 m.

The youngest unit in the sequence is the Lindsay Formation, which has a thickness of up to 67 m, and is comprised of two members. The lower member (unnamed) consists of limestones. The upper member is represented by the Eastview Member in eastern Ontario and the Collingwood Member in south-central and southwestern Ontario. The unit consists of up to 10 m of limestones and calcareous shales.

6.3.3.1 Rockcliffe Hydrogeologic Unit

A total of 2,117 wells have been identified within the Rockcliffe hydrogeologic unit. Of these, a sample of 1,771 wells was selected to determine the specific capacity and transmissivity distributions for the wells within the unit.

The minimum and maximum specific capacity values are 0.08 and 1,069.00 l/min/m, respectively. The 10 and 90 percentile values are 1.29 and 49.72 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 7.99 l/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.10 and 2,906.00 m^2/day, respectively. Figure A3 (Appendix II) is a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 2.13 and 103.90 m^2/day, and the geometric mean of the sample's transmissivity distribution is 15.52 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Rockcliffe hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a good water-yielding capability.

6.3.3.2 Ottawa Group Hydrogeologic Unit

A total of 10,357 wells have been identified within the Ottawa Group hydrogeologic unit. Of these, a sample of 7,251 wells was selected to determine the specific capacity and transmissivity distributions for the wells within the unit.

The minimum and maximum specific capacity values are 0.04 and 2,610.00 l/min/m, respectively. The 10 and 90 percentile values are 0.77 and 33.90 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 5.97 l/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.047 and 8,082.00 m^2/day, respectively. Figure A4 (Appendix II) is a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 1.27 and 70.94 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 11.70 m^2/day.

Given the large number of wells in the sample, it is possible to assume that sample's transmissivity distribution is representative of the water-yielding capability of the Ottawa Group hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a good water-yielding capability.

6.3.3.3 Simcoe Group Hydrogeologic Unit

An evaluation of the ground water resources of the Wilton Creek basin was carried out by Funk (1977). The Wilton Creek basin is located in southeastern Ontario about 20 km west of the City of Kingston. The bedrock in the basin consists of deposits of the Shadow Lake, Gull River, Bobcaygeon, and Verulam Formations. Funk (1977) reported on the results of pumping tests for a number of wells finished in the bedrock. The transmissivity values for these wells range from 1.34 to 58.15 m^2/day.

In this report, a total of 28,172 wells have been identified within the Simcoe Group hydrogeologic unit. Of these, a sample of 6,414 wells was selected to determine the specific capacity and transmissivity distributions for the wells within the unit. Figure 11 shows the locations of these wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values are 0.04 and 1,044.00 l/min/m. The 10 and 90 percentile values are 0.46 and 29.83 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 3.04 l/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.053 and 3,062.00 m^2/day, respectively. Figure A5 (Appendix II) is a transmissivity-probability graph showing the transmissivity distribution for the wells in the sample. The 10 and 90 percentile values are 0.71 and 63.84 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 5.70 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Simcoe Group hydrogeologic unit. The relatively low value of the distribution's geometric mean suggests that the water-yielding capability of the unit is fair.

6.3.4 Upper Ordovician Strata in Eastern and Central Ontario

The Upper Ordovician strata is represented in eastern Ontario by the Billings, Carlsbad and Queenston Formations, and in central Ontario by the Blue Mountain, Georgian Bay and Queenston Formations. These units consist mainly of shales.

The Billings Formation consists of shales with thin interbeddings of limestones. It has a thickness of up to 62 m. The Carlsbad Formation, with a maximum thickness of 186 m, is comprised of interbedded shales, siltstones and limestones. The Blue Mountain Formation consists of shales and has a maximum thickness of 60 m. The Georgian Bay Formation, with an average thickness of 100 m and a maximum thickness of 200 m, is comprised of shales with minor interbeds of siltstones and limestones.

The youngest unit in the Upper Ordovician sequence is the Queenston Formation with a thickness ranging from 45 to 335 m. The unit consists of shales with interbeds of limestones and calcareous siltstones.

6.3.4.1 Billings-Carlsbad-Queenston Hydrogeologic Unit

A total of 1,106 wells have been identified within the Billings-Carlsbad-Queenston hydrogeologic unit. Of these, a sample of 969 wells was selected to determine the specific capacity and transmissivity distributions for the wells within the unit.

The minimum and maximum specific capacity values are 0.05 and 745.00 l/min/m, respectively. The 10 and 90 percentile values are 0.59 and 24.81 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 4.47 l/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.06 and 1,803 m^2/day. Figure A6 (Appendix II) is a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 0.98 and 52.17 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 5.79 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Billings-Carlsbad-Queenston hydrogeologic unit. The relatively low value of the distribution's geometric mean suggests that the unit has a fair water-yielding capability.

6.3.4.2 Blue Mountain-Georgian Bay hydrogeologic unit

Ostry (1979) evaluated the hydrogeology of an area within the Duffins Creek and the Rouge River basins. The area is located in the Regional Municipality of Durham. Ostry (1979) provided estimates of the hydraulic conductivity values for 42 wells within the area, which were completed in the Blue Mountain Formation. The values range from 0.005 to 1.70 m/day, and the mean value is 0.29 m/day.

In their study of the ground water resources of the Credit River watershed, Singer el al (1994) indicated that ground water occurs in the upper 3-5 m of the Georgian Bay Formation. Further, the authors noted that only a few wells tap ground water in the formation, which they described as a poor aquifer. According to Singer et al (1994), the specific capacity values for wells completed in the Georgian Bay Formation range from 0.50 to 10.00 l/min/m, while the geometric mean of the formation's transmissivity distribution is 2.15 m^2/day.

In this report, the Blue Mountain and Georgian Bay Formations were treated as one hydrogeologic unit. A total of 2,130 wells have been identified within the unit. Of these, a sample of 1,293 wells was selected to determine the specific capacity and transmissivity distributions for the wells within the unit. Figure 12 shows the locations of water wells and the ranges of their specific capacities within the Blue Mountain-Georgian Bay and Queenston hydrogeologic units.

The minimum and maximum specific capacity values are 0.04 and 447.00 l/min/m, respectively. The 10 and 90 percentile values are 0.31 and 16.70 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 1.66 l/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.06 and 1,194.00 m^2/day, respectively. Figure A7 (Appendix II) is a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 0.49 and 36.52 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 2.93 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Blue Mountain-Georgian Bay hydrogeologic unit. The low value of the distribution's geometric mean suggests that the unit has a poor water-yielding capability.

6.3.4.3 Queenston Hydrogeologic Unit

According to Singer et al (1994), the pore spaces in the compact, dense shales of the Queenston Formation within the Credit River watershed have relatively poor interconnections. The unit does not readily fracture or dissolve thus limiting its effective porosity. Only the top 3-5 m are weathered and may provide sufficient water supplies to meet domestic needs. Singer et al (1994) also indicated that the specific capacity values for wells completed in the Queenston Formation within the Credit River watershed range from less than 0.50 to 20.00 l/min/m, while the geometric mean of the transmissivity distribution for wells completed in the formation equals 5.00 m^2/day.

Dames and Moore, Canada (1992) indicated that on the west side of the Credit River, from Terra Cotta to Inglewood, a number of domestic wells obtain their water from the Queenston Formation. These wells generally produce about 10.00 l/min using the maximum available drawdown, often to the bottom of the well.

In this report, a total of 3,580 wells were identified within the Queenston hydrogeologic unit in central Ontario. Of these, a sample of 2,505 wells was selected to determine the specific capacity and transmissivity distributions for the wells within the unit (Figure 12).

The minimum and maximum specific capacity values are 0.61 and 1,491.00 l/min/m, respectively. The 10 and 90 percentile values are 0.29 and 14.91 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 1.49 l/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.08 and 4,357 m^2/day, respectively. Figure A8 (Appendix II) is a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 0.47 and 27.95 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 2.66 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Queenston hydrogeologic unit. The low value of the distribution's geometric mean suggests that the unit has a poor water-yielding capability.

6.3.5 Lower Silurian Strata

Overlying the Ordovician rocks are formations comprised mainly of dolostones, shales, limestones and sandstones of Lower Silurian age. In southwestern Ontario, the Lower Silurian is represented by the Cataract Group, which includes the Whirlpool, Manitoulin, Cabot Head and Grimsby Formations.

The Whirlpool Formation outcrops along the Niagara Escarpment and is comprised of up to 9 m of sandstones. The Manitoulin Formation outcrops along the Niagara Escarpment and occurs extensively in the subsurface of southwestern Ontario. It consists of dolostones with a maximum thickness of 25 m.

The Cabot Head Formation occurs throughout southwestern Ontario and the Niagara Peninsula. It consists of 10 to 39 m of non-calcareous shales with minor calcareous sandstones, dolostones and limestones. The sandstones and shales of the Grimsby Formation overlie the Cabot Head Formation in the Niagara Peninsula and have a maximum thickness of 15.8 m. The formation thins northward and has not been identified north of Hamilton.

6.3.5.1 Cataract Group Hydrogeologic Unit

Singer et al (1994), in their evaluation of the ground water resources of the Credit River watershed, noted that the specific capacity values of wells completed in the Manitoulin Formation of the Cataract Group range from 1.50 to 20.00 l/min/m. The geometric mean of the transmissivity distribution of wells completed in the formation equals 4.00 m^2/day. Singer et al (1994) concluded that the Manitoulin Formation does not constitute an important aquifer in the Credit River watershed.

Within the Niagara Peninsula, all the formations of the Cataract Group are buried under thick sequences of younger rocks. From a hydrogeologic point of view, the Cataract Group hydrogeologic unit is of limited significance as a source of ground water.

6.3.6 Middle Silurian Strata

The Middle Silurian sequence is represented by the Dyer Bay, Wingfield and St. Edmund Formations; the Clinton Group (Thorold, Neahga, Reynales, Irondequoit, Rochester and Decew Formations); and the Fossil Hill, Amabel, Lockport and Guelph Formations. The major types of rocks are dolostones, shales, and sandstones.

The Dyer Bay Formation, which consists of dolostones, has an average thickness of 2 to 4 m and a maximum thickness of 7.6 m. The unit outcrops in the Bruce Peninsula and has been reported in the subsurface in Essex and Kent Counties.

The Wingfield Formation was identified in the Bruce Peninsula and consists of shales and dolostones ranging in thickness from 2 to 15 m. The St. Edmund Formation has also been identified in the Bruce Peninsula. It has a thickness of about 3 m and consists of dolostones.

The Thorold Formation, which has an average thickness of 3 metres and a maximum thickness of 6.5 m, has been identified in the Niagara peninsula and in the area of east-central Lake Erie. The unit consists of sandstones.

The Neahga Formation has been identified in the Niagara Peninsula. The unit consists of shales with minor limestone interbeds and has a maximum thickness of 2 m.

The Reynales Formation has been identified in the Niagara Peninsula and in the subsurface of southwestern Ontario. It consists of dolostones and dolomitic limestones with silty and/or shaly interbeds. The maximum thickness of the unit is 5 m.

The Irondequoit Formation has been identified in the Niagara Peninsula and in the subsurface of southwestern Ontario. The unit consists of limestones that are locally dolomitic and has a maximum thickness of 3 m.

The Rochester Formation has been identified in the Niagara Peninsula and in the subsurface of southwestern Ontario. The unit consists of shales and siltstones with carbonate interbeds. It has a maximum thickness of 24 m.

The Decew Formation, which has a thickness of up to 4 m, has been identified in the Niagara Peninsula. The unit is composed of dolostones with an increasing shale content towards the base of the formation.

The Fossil Hill Formation has been identified in the Bruce Peninsula and in the subsurface of southwestern Ontario. It consists of dolostones with a maximum thickness of 24 m.

The Amabel Formation has been identified in an area, which extends from the Bruce Peninsula in the north to Burligton in the south as well as in the subsurface of southwestern Ontario. It consists of dolostones up to 38 m thick.

The Lockport Formation has been identified in the Niagara Peninsula and in the subsurface of southwestern Ontario. The unit consists of three members: the Gasport Member (up to 10 m in thickness), the Goat Island Member (a maximum thickness of 16 m), and the Eramosa Member (a maximum thickness of 20 m). The Gasport Member is made up of dolomites and limestones, while the Goat Island and Eramosa Members are dolostones.

The youngest unit in the Middle Silurian sequence is the Guelph Formation, which has been identified in the Niagara and Bruce Peninsulas. The unit is composed of dolostones and has a highly variable thickness ranging from 4 to 100 m.

6.3.6.1 Dyer-Wingfield-St. Edmund Hydrogeologic Unit

Although no data related to this hydrogeologic unit are available, it is possible to assume, based on the types of rocks found in the unit, that it may acts as an aquifer in the Bruce Peninsula area.

6.3.6.2 Clinton Group Hydrogeologic Unit

The dolostones of the Decew Formation, which occur at the base of the Lockport Formation in the Niagara Peninsula, are most likely a part of the Lockport aquifer. The shales of the Rochester Formation, which occur under the Decew Formation in the same area, have much lower permeability and likely act as a barrier, diverting ground water flow within the overlying, younger deposits into a horizontal direction.

The remaining formations within the Clinton Group are buried under thick sequences of younger rocks in the Niagara Peninsula as well as in the subsurface in southwestern Ontario. Therefore, it is possible to conclude that the Clinton Group hydrogeologic unit is of little significance as a source of ground water in southern Ontario.

6.3.6.3 Amabel-Lockport-Guelph Hydrogeologic Unit

Four maps, which describe ground water flow within this hydrogeologic unit, were published by Turner in 1976 and 1978. The maps cover an area that extends from the Niagara River to Owen Sound. According to Turner (1976), the Amabel, Lockport and Guelph Formations constitute a high-capacity aquifer in the Niagara Peninsula and in the area between Hamilton and Owen Sound.

The permeability of the Amabel, Lockport and Guelph aquifer is highly variable, and is due primarily to fracturing and chemical dissolution of the upper few meters of dolomites. Most domestic wells obtain adequate water supplies with penetrations of less than 3 m, and the potential for developing high-capacity wells in the aquifer is good (Turner, 1976).

In the assessment of the water resources in the East and Middle Oakville Creeks basins, Funk (1979) described the Amabel Formation as one of the most important and productive bedrock aquifers in Ontario, and noted that the water yield of the formation is dependent on the degree of fracturing and available drawdown.

The transmissivities of five municipal wells, completed in the Amabel formation, were reported by Funk (1979) to range from 150.00 to 1,400.00 m^2/day. The coefficients of storage for the same wells range from 10^{-8} to 10^{-2}. Two of the five wells are located in Acton, two in Rockwood and one in Campbellville.

Sibul et al (1980) indicated that domestic supplies can be obtained readily throughout the Amabel-Lockport-Guelph aquifer; and high- capacity, municipal wells that tap the aquifer provide water supplies for the cities of Cambridge, Guelph and many other smaller towns. Areas containing highest well yields, outside of the major urbanized areas, are located in the vicinity of the towns of Fergus-Elora, Arthur and Dundalk, and in Puslinch, Erin, Amaranth and East Luther Townships.

According to Sibul et al (1980), the depths of wells in the Amabel-Lockport-Guelph aquifer are variable, depending on the overburden thickness. Generally, most of the domestic wells obtain water from the upper 15 m of the aquifer, while municipal and some industrial wells penetrate the bedrock to depths of 30 to 188 m.

Singer et al (1994) described the results of four pumping tests carried out in municipal wells that are completed in the Amabel Formation. One well is located in Mono Township, two wells in Erin, and one well in Orangeville. The values of the coefficients of transmissivity for the four wells range from 40.00 to 380.00 m^2/day. The values of the coefficients of storage, on the other hand, range from $3*10^{-4}$ to 10^{-1}.

Singer et al (1994) noted that because the Amabel Formation is fairly thick, its porosity and water-yielding capability are highly variable. These factors render the effective thickness of the aquifer to become considerably smaller than the measured thickness. This is to be expected in fractured bedrock.

In this report, a total of 23,559 wells have been identified within the Amabel-Lockport-Guelph hydrogeologic unit. Figure 13 shows the locations of these wells and the ranges of their specific capacities. Ground water occurrence within each of the three formations will be described separately.

A sample containing 6,516 wells was selected to determine the specific capacity and transmissivity distributions for wells completed in the Amabel Formation. The minimum and maximum specific capacity values for the sample are 0.05 and 2,908.00 l/min/m, respectively. The 10 and 90 percentile values are 0.91 and 59.66 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 7.85 l/min/m.

The minimum and maximum transmissivity values, derived from the specific capacity data for the sample, are 0.07 and 7,548.00 m^2/day, respectively. Figure A9 (Appendix II) shows a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 1.54 and 134.80 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 15.46 m^2/day.

A second sample of 1,662 wells was selected to determine the specific capacity and transmissivity distributions for wells completed in the Lockport Formation. The minimum and maximum specific capacity values for the second sample are 0.06 and 671.00 l/min/m, respectively. The 10 and 90 percentile values are 1.03 and 63.90 l/min/m, respectively, and the geometric mean of the second sample's specific capacity distribution is 10.63 l/min/m. The minimum and maximum transmissivity values, derived from the second sample's specific capacity data, are 0.09 and 1,879.00 m^2/day, respectively. Figure A9 shows a transmissivity-probability graph for the wells in second sample. The 10 and 90 percentile values are 1.69 and 141.00 m^2/day, respectively, and the geometric mean of the second sample's transmissivity distribution is 20.60 m^2/day.

A third sample of 6,072 wells was selected to determine the specific capacity and transmissivity distributions for wells completed in the Guelph Formation. The minimum and maximum specific capacity values for the third sample are 0.06 and 2,076.00 l/min/m, respectively. The 10 and 90 percentile values are 0.81 and 49.72 l/min/m, respectively, and the geometric mean of the third sample's specific capacity distribution is 6.21 l/min/m.

The minimum and maximum transmissivity values, derived from the specific capacity data for the third sample, are 0.09 and 5,719.00 m^2/day, respectively. Figure A9 shows a transmissivity-probability graph for the wells in the third sample. The 10 and 90 percentile values are 1.37 and 104.90 m^2/day, respectively, and the geometric mean of the third sample's transmissivity distribution is 12.05 m^2/day.

An examination of the specific capacities and transmissivity values of the Amabel, Lockport and Guelph Formations indicates that the values are highly variable, which is most likely a reflection of the variable distribution of fissure systems within these formations. Nevertheless, the 10 and 90 percentile values for both the specific capacity and transmissivity distributions for the three samples are within similar range. The same is also true for the geometric means of the three distributions.

Given the large number of wells used in the above three samples, it is possible to assume that the transmissivity distributions for the three samples are representative of the water-yielding capabilities of the Amabel, Lockport and Guelph Formations. The relatively high values of the geometric means of the three distributions suggest that the water-yielding capabilities of the three formations are good.

The Amabel, Lockport and Guelph Formations are made up mainly of dolostones and limestones. Due to the similarities among their specific capacity and transmissivity distributions, it is possible to treat the three formations as one hydrogeologic unit.

6.3.7 Upper Silurian Strata

The Upper Silurian sequence consists of the Salina Formation (Southwestern Ontario), the Bertie Formation (Niagara Peninsula) and the Bass Island Formation (Bruce Peninsula and subsurface of southwestern Ontario). The Bertie and Bass Island Formations appear to be of the same age.

The Salina Formation has been subdivided into 8 units, named A-1, A-2, and B through G. In general, these units consist of dolostones, evaporites, evaporitic carbonates and shales. The total maximum thickness of the Salina Formation is 330 m.

The Bertie Formation consists of up to 14 m of dolostones with numerous bituminous partings. The upper surface contains joints and fractures infilled with sandstones of the Oriskany Formation of Lower Devonian age.

The youngest Silurian strata in southern Ontario is represented by the Bass Island Formation, which consists of dolostones. Its thickness ranges from 22 to 28 metres.

6.3.7.1 Salina Hydrogeologic Unit

In the study of the ground water resources in the Grand River basin, Sibul et al (1980) described the Salina Formation as a high-capacity, water-supply source north of Kitchener-Waterloo. The authors also reported on substantial fracturing within the formation that was encountered in two test holes located south of Kitchener. Mud circulation could not be maintained in both test holes after approximately 1 m of penetrating the bedrock. According to Sibul et al (1980), the fracturing at both test holes is indicative of the high permeability of the Salina Formation.

In this report, a total of 3,756 wells have been identified within the Salina Formation. The depths of these wells may vary considerably due to large variations in overburden thickness. Once through the overburden, however, the wells penetrate generally less than 15 m into the Salina Formation. Figure 13 shows the locations of these wells and the ranges of their specific capacities.

A sample of 2,994 wells was selected to determine the specific capacity and transmissivity distributions for the wells within the Salina Formation. The minimum and maximum specific capacity values are 0.07 and 3,729.00 l/min/m, respectively. The 10 and 90 percentile values are 1.70 and 82.86 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 13.16 l/min/m.

The minimum and maximum transmissivity values, derived from the samples specific capacity data, are 0.10 and 10,197.00 m^2/day, respectively. Figure A10 (Appendix II) shows a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 3.16 and 189.00 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 28.18 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Salina hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a very good water-yielding capability.

6.3.7.2 Bass Island Hydrogeologic Unit

Only 16 wells have been identified within the Bertie Formation. This is insufficient to determine the hydrogeologic significance of this uint. Given that the Bertie Formation is similar in composition to the Bass Island Formation, it is possible to assume that the water-yielding capabilities of both formations are similar.

A total of 807 wells, have been identified within the Bass Island Formation. Of these, a sample of 739 wells was selected to determine the specific capacity and transmissivity distributions for the wells within the unit. Figure 13 shows the locations of these wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values are 0.29 and 5,599.00 l/min/m, respectively. The 10 and 90 percentile values are 2.98 and 47.57 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 14.91 l/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.43 and 14,219.00 m^2/day, respectively. Figure A10 (Appendix II) shows a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 5.44 and 179.00 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 30.92 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Bass Island hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a very good water-yielding capability.

6.3.8 Lower Devonian Strata

The Lower Devonian sequence in southern Ontario consists of the Oriskany Formation (Niagara Peninsula area), and the Bois Blanc Formation, which occurs in a narrow band extending from the Niagara Peninsula to Lake Huron. The Oriskany Formation consists of calcareous sandstones with a maximum thickness of 6 metres. The Bois Blanc Formation, which ranges in thickness from 3 to 50 metres, consists of cherty limestones that grade into dolostones towards the west.

No hydrogeologic data are available for the Oriskany Formation. Given its composition and small thickness, it is possible to assume that the formation is a minor aquifer.

6.3.8.1 Bois Blanc Hydrogeologic Unit

A total of 1,261 wells have been identified within the Bois Blanc hydrogeologic unit. Of these, a sample of 1,069 wells was selected to determine the specific capacity and transmissivity distributions for the wells within the unit. Figure 14 shows the locations of these wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values are 0.27 and 5,719.00 l/min/m, respectively. The 10 and 90 percentile values are 3.31 and 112.00 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 18.64 l/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.41 and 3,905.00 m^2/day, respectively. Figure A11 (Appendix II) is a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 6.28 and 274.50 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 40.45 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Bois Blanc hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests the unit has an excellent water-yielding capability.

6.3.9 Middle Devonian Strata

The Middle Devonian sequence includes the Onondaga Formation in the Niagara Peninsula and the corresponding Detroit River Group in southwestern Ontario, the Dundee and Marcellus Formations (southwestern Ontario), and the Hamilton Group (southwestern Ontario, from Lake Erie to St. Thomas area). The major types of rocks are limestones, dolostones, sandstones and shales.

The Onondaga Formation consists of three members: the Edgecliffe Member (limestones up to 21 m thick), the Clarence Member (cherty limestones, 5 to 8 m thick), and the Moorehouse Member (limestones, 4.5 m thick). No hydrogeologic data are available for the Onondaga Formation. Therefore, it is not possible to make any assumptions concerning its hydrogeologic significance.

The Detroit River Group consists of three formations: Sylvania, Amherstburg, and Lucas. The Sylvania Formation consists of up to 25 m of sandstones; the Amherstburg Formation consists of 40 to 60 m of limestones becoming dolostones towards the southwest; and the Lucas Formation consists of 40 to 75 m of limestones and dolostones.

Overlying the Lucas and Onondaga Formations, are the Dundee and Marcellus Formations. The Dundee Formation consists of limestones and has an average thickness of 35 to 45 m. The Marcellus Formation occurs between Port Stanley and Long Point on Lake Erie, and extends inland as far as Aylmer and St. Thomas. The unit consists mainly of shales and has a maximum thickness of 12 m.

The Hamilton Group contains six units: the Bell, Rockport Quarry, Arkona, Hungry Hollow, Widder, and Ipperwash Formations. The lowest unit in the Hamilton Group is the Bell Formation. With an average thickness of 14.5 m, the Bell Formation consists mainly of shales with thin, organic shale interbeds.

The Rockport Quarry Formation consists of limestones with shale interbeds. It has an average thickness of 5.7 m. The Arkona Formation consists of shales with occasional limestone interbeds. It has an average thickness of 32 m. The Hungry Hollow Formation consists of limestones and is about 2 m in thickness. The Widder Formation consists of shales with limestone interbeds. The unit has a maximum thickness of 21 m.

The upper-most member of the Hamilton Group is the Ipperwash Formation, which consists of limestones with minor cherts. The unit's thickness ranges from 2 to 13 m.

6.3.9.1 Detroit River Group Hydrogeologic Unit

A total of 7,818 wells have been identified to penetrate the rocks of the Detroit River Group. Of these, a sample of 6,762 was selected to determine the specific capacity and transmissivity distributions for wells within the unit. Figure 14 shows the locations of these wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values are 0.06 and 2,237.00 l/min/m, respectively. The 10 and 90 percentile values are 2.13 and 89.49 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 14.91 l/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.12 and 6,472.00 m^2/day, respectively. Figure A12 (Appendix II) shows a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 3.98 and 214.00 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 30.92 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Detroit River Group hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a very good water-yielding capability.

6.3.9.2 Dundee Hydrogeologic Unit

A total of 5,030 wells have been identified to penetrate the rocks of the Dundee Formation. Due to the high thickness of the overburden deposits along the northern shores of Lake Erie between Port Stanley and Long Point, only a few wells have been identified in the Dundee or Marcellus Formations in that area.

A sample of 4,199 wells was selected to determine the specific capacity and transmissivity distributions for wells within the Dundee hydrogeologic unit. Figure 14 shows the locations of these wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values are 0.07 and 3,281.00 l/min/m, respectively. The 10 and 90 percentile values are 1.65 and 74.57 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 13.05 l/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.08 and 9,380.00 m^2/day, respectively. Figure A12 (Appendix II) shows a transmissivity-probability graph for the sample. The 10 and 90 percentile values are 3.09 and 169.10 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 27.08 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Dundee hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a very good water-yielding capability.

6.3.9.3 Hamilton Group Hydrogeologic Unit

A total of 2,208 wells have been identified to penetrate the rocks of the Hamilton Group. Of these, a sample of 1,044 wells was selected to determine the specific capacity and transmissivity distributions for the wells within the unit. Figure 14 shows the locations of these wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values are 0.07 and 1,007.00 l/min/m, respectively. The 10 and 90 percentile values are 0.32 and 27.70 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 2.71 l/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.11 and 2,638.00 m^2/day, respectively. Figure A12 (Appendix II) shows a transmissivity-probability graph for the sample. The 10 and 90 percentile values are 0.55 and 63.45 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 5.33 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Hamilton Group hydrogeologic unit. The relatively low value of the distribution's geometric mean suggests the unit has a fair water-yielding capability.

6.3.10 Upper Devonian and Mississipian Strata

The Kettle Point Formation represents the youngest strata in the Devonian sequence in southern Ontario. The unit, which extends from Lake Erie (Chatham area) to Lake Huron (Sarnia area), has a thickness ranging from 30 to 75 m and consists mainly of shales and siltstones.

The Port Lambton Group has been identified in the subsurface in a small area in Lambton County. Its age is either Upper Devonian or Early Mississipian. Three formations have been identified in the Port Lambton Group: the Bedford, Berea and Sunbury.

The Bedford Formation consists of 30 m of shales with silty and sandy interbeds in the upper part of the unit. The Berea Formation (60 m) consists of sandstones, which are interbedded with shales and siltstones. The Sunbury Formation consists of shales and has a maximum thickness of 20 m.

6.3.10.1 Kettle Point Hydrogeologic Unit

No hydrogeologic information is available for the Port Lambton Group. Given its shaly composition and its small spatial extent, the Port Lambton Group is of minor significance as a source of ground water.

A total of 6,145 wells have been identified within the Kettle Point hydrogeologic unit. Of these, a sample of 3,096 wells was selected to determine the specific capacity and transmissivity distributions for the wells within the unit. Figure 14 shows the locations of these wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values are 0.05 and 745.70 l/min/m, respectively. The 10 and 90 percentile values are 0.49 and 37.29 l/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 4.17 l/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.07 and 1,675.00 m^2/day, respectively. Figure A13 (Appendix II) is a transmissivity-probability graph for the sample. The 10 and 90 percentile values are 0.90 and 82.85 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 8.57 m^2/day.

Given the large number of wells in the sample, it is possible to assume that the sample's transmissivity distribution is representative of the water-yielding capability of the Kettle Point hydrogeologic unit. The relatively low value of the distribution's geometric mean suggests that the unit has a fair water-yielding capability.

6.4 A COMPARISON OF THE WATER-YIELDING CAPABILITIES AMONG VARIOUS BEDROCK HYDROGEOLOGIC UNITS

Table 2 and Figure 15 provide a summary and a graphical display of the water-yielding capabilities of various bedrock, hydrogeologic units in southern Ontario. To assess the water-yielding capabilities of the various units, a qualitative scale was used. The scale, which is based on the ranges of the geometric means of the transmissivity distributions for the units, is as follows:

Geometric mean m^2/day	Water-yielding capability
less than 5	poor
5 - 10	fair
10 - 20	good
20 - 30	very good
30 - 40	excellent

Based on the above scale, the Bois Blanc, Detroit River, Salina, Bass Island, Dundee, and Amabel-Lockport-Guelph hydrogeologic units have been identified as the best water-yielding units within the bedrock of southern Ontario.

7. GROUND WATER OCCURRENCE IN THE OVERBURDEN

Most of the Palaeozoic rocks in southern Ontario are obscured by a mantle of unconsolidated sediments, also known as the overburden. The overburden was deposited during the Quaternary Period.

The Quaternary Period has been subdivided into the Pleistocene (Great Ice Age) and Holocene (Recent) epochs. The Pleistocene Epoch is the period when great ice sheets covered parts of Ontario several times. The Holocene Epoch includes postglacial times, up to and including the present.

The ice advances and recessions during the Quaternary Period have played a major role in shaping the landscape of southern Ontario and have left behind a variety of unconsolidated deposits consisting of tills, gravels, sands, silts, and clays.

The Quaternary deposits of southern Ontario are associated with the two main glacial stages of the Pleistocene Epoch, the Illinoian and Wisconsinan as well as with the interglacial Sangamonian Stage and the Holocene Epoch. Sediments deposited prior to the Late Wisconsinan substage in southern Ontario are rarely at the surface and are observed mainly in man-made excavations. Exposures of sediments of the Late Wisconsinan, however, are widespread and have been extensively investigated. Figure 16 is a correlation chart of Wisconsinan deposits in southwestern Ontario (Thurston et al, 1992).

Barnett (1992) provided a comprehensive description of the Quaternary geology of southern Ontario and compiled an extensive list of references related to this topic. In this report, the geologic descriptions of various overburden units in southern Ontario are based on Barnett (1992), and will be given according to geographic location and in order of oldest to youngest unit.

The description of overburden hydrogeology, on the other hand, is based on the characteristics of water wells completed in various overburden units. The OSG Map 2556, scale 1:1,000,000 (Barnett et al, 1991) was used to delineate the geologic boundaries of the units at the surface.

The reasons for concentrating attention on the wells rather than the overburden units are based on the following:

1. At the regional scale of mapping, it is extremely difficult to determine with any degree of certainty the hydraulic parameters of individual overburden units. This is due to the fact that the overburden is highly variable in terms of composition and thickness both vertically and horizontally.

2. A well could penetrate a number of tills, silts, sands or gravels, and it is not always clear which one of these materials contributes most of the water to the well.

Faced with these difficulties, the descriptions of ground water occurrence in various overburden units is provided in terms of the characteristics of wells that have been completed in areas where these units outcrop at the surface. No statements, however, are made regarding the significance of water-yielding capabilities of the various units.

Figure 17 shows the locations of wells completed in the overburden. The figure indicates that most of these wells are located in central and southwestern Ontario where the thickness of the overburden can be substantial.

In this report, the records of 82,232 wells completed in the overburden were examined. Of these, a total of 43,321 wells that have the highest degree of accuracy in terms of well location and elevation, were selected to determine the ranges of their specific capacity values. Table 3 gives the number of overburden wells by county and the kind of water encountered in these wells in terms of being fresh, salty, sulphurus, mineral or containing gas.

7.1 OVERBURDEN THICKNESS

Figure 18 shows the spatial distribution of overburden thickness in southern Ontario. The figure indicates that the thickness of the overburden is quite variable. The overburden is very thin over the Canadian Shield, along the Niagara Escarpment, and over most of the eastern parts of southern Ontario.

In the central parts of southern Ontario, within the Oak Ridges moraine and in the area between Lake Simcoe and Georgian Bay, the overburden is over 110 m in thickness. Above the Niagara Escarpment, the overburden thickness ranges from less than 10 m where the bedrock is close to surface to over 110 m within the Waterloo moraine.

Thick overburden deposits (30-90 m) are found within an area extending along the northern shores of Lake Erie from Long Point Bay to Blenheim. The overburden is also thick within the numerous moraines and kames that are scattered throughout southwestern Ontario. The overburden thickness within most of these landforms ranges from 30 to 70 m and it is greater than 110 m within the Waterloo moraine.

In this report, the thickness of various overburden deposits is given when available from literature.

7.2 ILLINOIAN GLACIAL DEPOSITS

The York Till (clayey sand till), found in Toronto and Woodbridge, and the Bradtville drift, encountered in boreholes along the northern shores of Lake Erie, are probably the oldest Quaternary deposits in southern Ontario. It is believed that they were deposited during or possibly before the Illinoian Glaciation. According to Karrow (1984), the thickness of the York Till in the Toronto area ranges from 0 to 6 m.

In regional terms, the Illinoian glacial deposits may be of limited hydrogeologic significance due to their limited spacial extent.

7.3 SANGAMONIAN INTERGLACIAL DEPOSITS

The Sangamonian Interglacial deposits are represented by the Don Formation, which has been identified in the Scarborough Bluffs east of Toronto, in the Don Brickyard in Toronto and in Woodbridge. The Don Formation ranges in thickness from 0 to 18 m (Karrow, 1984) and is believed to have been deposited under warm climatic conditions similar to those of today. The unit consists of gravels, sands, silts and clays, and is probably of deltaic origin.

In regional terms, the Sangamonian Interglacial deposits may be of limited hydrogeologic significance due to their limited spatial extent.

7.4 EARLY WISCONSINAN DEPOSITS

The best documented Early Wisconsinan deposits are found in the Scarborough Bluffs, in the Don Brickyard in Toronto and in Woodbridge. These deposits belong to three stratigraphic units: the Scarborough Formation , the Pottery Road Formation and the Sunnybrook drift. The Canning Till, found in the Hamilton area, is also believed to be of Early Wisconsinan age.

The Scarborough Formation (3-30 m thick, Karrow, 1984) consists of clay and silt rythmites at the base, and of cross-bedded sands at the top. It is believed that the unit is of deltaic origin.

The Pottery Road Formation (0-7 m thick, Karrow, 1984) consists of gravels and gravely sands. The units occurs within channels, which cut the Scarborough and Don Formations, and is probably of alluvial origin.

The Sunnybrook drift (3-24 m thick, Karrow, 1984) consists of a lower member termed the Sunnybrook Till and an upper member termed the Bloor Member. The Scarborough Till is a silt to silty-clay till, 6 to 10 m in thickness. The Bloor Member consists of varved clays. The Scarborough and Pottery Road Formations constitute local aquifers. Data, however, are not adequate to describe the exact spatial extent of these aquifers.

7.5 MIDDLE WISCONSINAN DEPOSITS

The Middle Wisconsinan deposits are represented by the Thorncliffe Formation in the Scarborough Bluffs, and the Tyconnell and Wallacetown Formations in the Lake Erie basin.

The Thorncliffe Formation is approximately 47 m in thickness (Karrow, 1984) and is composed of stratified sediments of sands, silts and clays of both glaciofluvial and glaciolacustrine origin. Two tills have been identified in the Scarborough Bluffs: the silty Seminary Till and the clayey Meadocliffe Till. These two tills separate the Thorncliffe Formation into a Lower, Middle, and Upper Members. The tills, however, appear to pinch out farther inland and the Thorncliffe Formation becomes a continuous unit.

The Middle Wisconsinan deposits in the Lake Erie basin consist of a buried soil and two main organic-bearing units, each separated by glaciolacustrine sediments.

The sands of glaciofluvial and glaciolacustrine origin within the Thorncliffe Formation constitute aquifers of local significance. Ground water issuing at the base of these sands in the form of small springs is one important factor, which is continuously undermining the stability of the Scarborough Bluffs.

7.6 LATE WISCONSINAN DEPOSITS AND CHARACTERISTICS OF WATER WELLS IN AREAS WHERE THESE DEPOSITS OUTCROP AT THE SURFACE

According to Barnett (1992), three significant periods of ice advance directly affected the Lower Great Lakes region during the Late Wisconsinan. These periods were termed the Nissouri, Port Bruce, and Port Huron stades. Two warm periods: the Erie and Mackinaw interstades, characterized by ice-margin recession, separated the three stades.

The Port Huron Stade was followed by a warm period known as the Two Creeks Interstade. This, in turn, was followed by a minor and final ice advance known as the Greatlakean Stade.

7.6.1 Nissouri Stadial Deposits

The Nissouri Stadial deposits are represented by the Catfish Creek and the Dunwich Tills. The Catfish Creek Till is widespread in the subsurface throughout southwestern Ontario. This sandy silt to silt till outcrops along Catfish Creek near Sparta, in the Lake Erie Bluffs near Port Talbot, and in the vicinity of Woodstock and Dundalk. The Dunwich Till, on the other hand, is believed to be a Huron lobe facies of the Catfish Creek Till.

7.6.1.1 Catfish Creek Till

A total of 206 wells were identified in areas where the Catfish Creek Till outcrops at surface. No dry wells have been reported. General information related to quality of ground water is available for 201 wells. All these wells have been reported to yield fresh water.

A sample of 167 wells was selected to determine the statistical parameters for the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.36
10 percentile	1.36
mean	8.77
90 percentile	44.74
maximum	223.70

7.6.2 Erie Interstadial Deposits

Warm climatic conditions prevailed during the Erie Interstade resulting in an ice-marginal recession in the Lakes Michigan, Huron, and Erie basins, and in the formation of a series of ice-contact proglacial lakes. Most of the records of these lakes, however, were destroyed by subsequent events.

A thick sequence of glaciolacustrine rythmites in the central part of the Lake Erie basin termed the "Malihide Formation", and deposits of silts termed the "Wildwood Silts" near St. Marys have been assigned to the Erie Interstade.

No information is available to evaluate the hydrogeologic significance of the Erie Interstadial deposits.

7.6.3 Port Bruce Stadial Deposits

During the Port Bruce Stade, ice sheets advanced radially across southern Ontario from Georgian Bay and Lakes Huron, Erie, Ontario and Simcoe. The ice lobes advanced, laid down numerous tills, and formed moraines. The Ingersoll, Waterloo and Orangeville moraines mark the northern extent of the Erie-Ontario lobe tills, while the Blenhiem, Ingersoll, Waterloo and Orangeville moraines mark the eastern and southern advance of the Huron-Georgian Bay lobe tills.

7.6.3.1 Deposits Associated with the Combined Erie-Ontario Lobe

The Maryhill Till, and Port Stanley Drift represent the fluctuations of the Erie-Ontario lobe. The Maryhill Till has been identified beneath Port Stanley Drift in an area between Woodstock and Kitchener. It is a calcareous, silty clay to clay till.

Along the north-central shores of Lake Erie, the Port Stanley Drift consists of up to five layers of clayey silt to silty clay till, termed the Port Stanley Till. Those till layers are separated by glaciolacustrine sediments. Farther inland, the five layers of till merge into one layer of silt to sandy silt type till, while the glaciolacustrine deposits become glaciofluvial.

7.6.3.1.1 Maryhill Till

A total of 375 wells were identified in small areas located to the southwest of Kitchener where the Maryhill Till outcrops at surface. Seven wells have been reported as being dry.

A sample of 241 wells was selected to determine the statistical parameters for the sample's specific capacity distribution. The results are as follows:

Parameter	Specific Capacity l/min/m
minimum	0.37
10 percentile	2.73
mean	5.06
90 percentile	79.30
maximum	809.00

The relatively high values of the specific capacities of some wells within the sample are most likely the result of the wells tapping ground water in the sands and gravels associated with the Waterloo moraine.

7.6.3.1.2 Port Stanley Till

A total of 5,191 wells have been identified in areas where the Port Stanley Till outcrops at surface. Of these, 107 wells have been reported to be dry.

General information related to the quality of ground water is available for 4,702 wells. Approximately, 99% of these wells yield fresh water, and the remaining 1% yield mainly sulphurous water.

A sample of 3,651 wells was selected to determine the statistical parameters for the sample's the specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.06
10 percentile	1.19
mean	7.15
90 percentile	44.74
maximum	1551.00

7.6.3.2 Deposits Associated with the Combined Huron-Georgian Bay Lobe

Five tills were lain down by the combined Huron-Georgian Bay lobe. These are the Stirton, Tavistock, Mornington, Stratford and Wartburg Tills.

The Stirton Till occurs in the subsurface within the Conostogo River valley. This calcareous, silty clay to clayey silty till, has a thickness of 1 to 3 m. No water wells associated with the the Stirton Till have been identified.

South of Lake Huron and Lake St. Clair, the Tavistock Till is a calcareous, silty clay to clay silt till, 2 to 15 m thick. The till changes into a calcareous, silt to sandy silt to sand till in the London and Woodstock area; and into a calcareous, silty clay to silt till in an area to the north of Waterloo.

The Mornington Till is a calcareous, silty clay till. It occurs at surface to the northwest of Waterloo as a sheet of ground moraine, 1 to 3 m thick.

The Stratford Till is a calcareous, sandy silt to silt till. It is a sheet of ground moraine, 1 to 3 m thick. It occurs at surface to the north and southeast of Stratford.

The Wartburg Till is a calcareous, silty clay till, 2 to 15 m thick. It forms the core of the Milverton moraine, which is located to the west of Waterloo. No wells that are associated with the Wartburg Till have been identified.

7.6.3.2.1 Tavistock Till

A total of 2,525 wells were identified in areas where the Tavistock Till outcrops at surface. Sixty three of these wells have been reported to be dry.

General information related to the quality of ground water is available for 2,315 wells. Approximately, 98% of these wells yield fresh water, and the remaining 2% yield either sulphurous or salty water.

A sample of 1,678 wells was selected to determine the statistical parameters for the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
Minimum	0.13
10 percentile	1.57
mean	10.44
90 percentile	62.14
maximum	2237.00

7.6.3.2.2 Mornington Till

A total of 395 wells have been identified in areas where the Mornington Till outcrops at surface. Of these, 6 wells have been reported to be dry.

General information related to the quality of ground water is available for 368 wells. Approximately, 97% of these wells yield fresh water, and the remaining 3% yield either salty or mineral water.

A sample of 281 wells was selected to determine the statistical parameters for the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.78
10 percentile	2.38
mean	4.91
90 percentile	62.13
maximum	358.00

7.6.3.2.3 Stratford Till

A total of 131 wells have been identified in areas where the Stratford Till outcrops at surface. Two of these wells have been reported to be dry. General information related to the quality of ground water is available for 125 wells. All the wells have been reported to yield fresh water.

A sample of 86 wells was selected to determine the statistical parameters for the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.83
10 percentile	2.71
mean	5.95
90 percentile	55.92
maximum	746.00

7.6.3.3 Deposits Associated with the Georgian Bay Lobe

Two tills were lain down by the Georgian Bay lobe: the Elma Till and the Dunkeld Till. The Elma Till is a calcareous, silt, sandy silt and clayey silt till. It ranges in thickness between 2 and 15 m and covers a wide area extending from Owen Sound to Stratford. The Elma Till occurs as ground moraine and in the drumlins of the Teeswater drumlin field, and is also associated with the Singhampton moraine.

The Dunkeld Till outcrops as a ground moraine within a small area in the Saugeen River valley. The unit is a calcareous silt till.

7.6.3.3.1 Elma Till

A total of 557 wells were identified in areas where the Elma Till outcrops at surface. Of these, 21 wells have been reported to be dry.

General information related to ground water quality is available for 494 wells. Approximately, 99% of these wells yield fresh water, and the remaining 1% yield either salty or sulphurous water.

A sample of 392 wells was selected to determine the statistical parameters for the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.11
10 percentile	1.35
mean	6.06
90 percentile	59.65
maximum	671.00

7.6.3.3.2 Dunkeld Till

A total of 16 wells have been identified in areas where the Dunkeld Till outcrops at surface. All the wells yield fresh water. It was not possible to select a suitable sample for statistical analysis.

7.6.3.4 Deposits Associated with the Huron Lobe

The Rannoch Till was laid down by the Huron lobe. It outcrops over a large area, extending from the St. Clair River to the headwaters of the Maitland River. The till occurs as ground moraine and in a number of end moraines including the Mitchell, Dublin, Lucan, Seaforth and Centralia moraines. It is a calcareous, silt to silty clay till with an average thickness of 2 to 6 m and a maximum thickness of 75 m.

7.6.3.4.1 Rannoch Till

A total of 2,638 wells have been identified in areas where the Rannoch Till outcrops at surface. Of these, 112 wells have been reported to be dry.

General information related to the quality of ground water is available for 2,291 wells. Approximately, 99% of these wells yield fresh water, and the remaining 1% yield either sulphurous or salty water.

A sample of 1,530 wells was selected to determine the statistical parameters for the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.15
10 percentile	1.42
mean	9.32
90 percentile	67.79
maximum	895.00

7.6.3.5 Deposits Associated with the Simcoe Lobe

The Newmarket Till was deposited by the Simcoe lobe. It is a calcareous, silt to sandy silt till, which is less than 3 to 12 m in thickness. It outcrops in the Holland and Nottawasaga Rivers basins as ground moraine; and above the Niagara Escarpment as hummocky end moraines. The till is often covered by glaciofluvial and glaciolacustrine sands and silts.

7.6.3.5.1 Newmarket Till

A total of 3,762 wells have been identified in areas where the Newmarket Till outcrops at surface. Of these, 83 wells have been reported to be dry.

General information related to the quality of ground water is available for 3,153 wells. Over 99.8% of these wells yield fresh water, and the remaining 0.2% of the wells yield either salty or sulphurous water.

A sample of 1,791 wells was selected to determine the statistical parameters for the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.07
10 percentile	0.99
mean	4.52
90 percentile	24.86
maximum	915.00

7.6.3.6 Glaciofluvial and Glaciolacustrine Deposits Associated with the Port Bruce Stade

During the Port Bruce Stade, ice-margin recessions caused ponding of meltwaters several times in the western end of the Lake Erie basin and in the southern end of the Lake Huron basin. This resulted in the formation of glacial lakes termed Maumee I, II, III and IV. These glacial lakes and the rivers that flowed into them left large amounts of glaciofluvial and glaciolacustrine deposits. The occurrence of ground water in these deposits is discussed as part of the descriptions of various glaciofluvial and glaciolacustrine deposits.

7.6.4 Mackinaw Interstadial Deposits

During a warming period, the retreat of the ice continued and a glacial Lake Arkona formed in the combined Lakes Huron and Erie basins. The Wentworth Till is believed to have been deposited during this period as a result of a readjustment of the Erie-Ontario lobe margin.

The Wentworth till occurs as ground moraine, drumlins and moraines. The Paris, Galt and Moffat moraines consist of Wentworth Till. In the north where the Wentworth Till is associated with outwash gravels and sands, it is a calcareous, sandy silt till. It becomes a clay to silty clay till, however, in the south along the Lake Erie shoreline.

During the later parts of the Mackinaw Interstade, the Lake Ontario lobe started to separate from the Simcoe lobe and the Oak Ridges moraine began to form. In addition, glaciofluvial outwash sediments were deposited in front of the Paris and Galt moraines as well as to the south of the Singhampton and Gibraltar moraines. The ground water occurrence in these deposits is discussed as part of the description of glaciofluvial deposits.

7.6.4.1 Wentworth Till

A total of 873 wells have been identified in areas where the Wentworth Till outcrops at surface. Of these, 8 wells have been reported to be dry.

General information related to the quality of ground water is available for 838 wells. Approximately, 99.5% of the wells yield fresh water, and the remaining 0.5% yield either sulphurous or salty water.

A sample of 662 wells was selected to determine the statistical parameters for the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.16
10 percentile	2.82
mean	6.57
90 percentile	74.57
maximum	298.00

7.6.5 Port Huron Stadial Deposits

The readvance of the ice margin during Port Huron Stade into the eastern end of Lake Erie and the southern end of Lake Huron resulted in the deposition of a number of tills. The Halton Till was deposited by the Erie-Ontario lobe, the Kettleby Till by the Simcoe lobe, and the St. Joseph Till by the Huron and Georgian Bay lobes.

The Halton Till occurs as ground moraine over a large area to the north of Lake Ontario, extending from Hamilton through Georgetown and Aurora to Orono. The till also occurs in a series of low-relief end and recessional moraines in the Niagara Peninsula area. To the north of Lake Ontario, the Halton Till is primarily a sandy silt to silt till. However, it is a clayey silt to silty clay till in the Niagara Peninsula.

The Kettleby Till was deposited by the Simcoe lobe and occurs as a discontinuous sheet of ground moraine to the north of the Oak Ridges moraine and above the Niagara Escarpment. It is a calcareous, silty clay to clay till less than 2 m thick.

The St. Joseph Till is a calcareous, silt to silty clay till. The till covers an area, which extends mostly along the shores of Lake Huron from the Saugeen River in the north to the St. Clair River in the south. The till occurs as ground moraine and is found within the Wyoming, Banks and Williscroft moraines.

During the Port Huron Stade a number of proglacial lakes were formed in the Lake Erie-Huron basin including: Lake Whittlesey, Lake Warren, Lake Lundy, Lake Peel and Lake Schomberg. A variety of sediments, which are associated with those proglacial lakes, were deposited, including:

- shoreline deposits that are associated with Lake Whittlesey to the north of Lake Erie;
- deltaic deposits that are associated with Lake Whittlesey at Bradford and west of London;
- shoreline deposits that are associated with Lake Warren at Leamington, Ridgetown and along the Wyoming moraine;
- glaciolacustrine sediments including the sand plains of Norfolk, Caradoc and Bothwell, and the clay plains of St. Clair and Haldimand; and
- thick clay and silt rythmites that are associated with Lake Schomberg.

Ground water occurrence in the Port Huron Stadial deposits is discussed as part of the description of the glaciofluvial and glaciolacustrine deposits.

7.6.5.1 Halton Till

Funk (1979) described the Halton Till in the East and Middle Oakville Creeks as being an aquitard, which is a water-bearing geologic unit that does not yield or transmit water readily.

Singer et al (1994) described the Halton Till in the Credit River watershed as being a poor aquifer. The specific capacities for 216 wells, completed in the Halton Till, were found to range from 0.30 to 60.00 l/min/m.

In this report, a total of 9,598 wells have been identified in areas where the Halton Till outcrops at surface. Of these, 274 wells have been reported to be dry.

General information related to the quality of ground water is available for 8,214 wells. The majority of these wells yield fresh water, 15 wells yield salty water, and 14 wells yield either sulphurous or mineral water.

A sample of 5,576 wells was selected to determine the statistical parameters for the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.35
10 percentile	0.88
mean	4.30
90 percentile	29.83
maximum	299.30

7.6.5.2 Kettleby Till

A total of 1,312 wells have been identified in areas where the Kettleby Till outcrops at surface. Of these, 40 wells have been reported to be dry.

General information related to the quality of ground water is available for 865 wells. One well yields sulphurous water, one well yields mineral water, and the remaining 863 wells yield fresh water.

A sample of 569 well was selected to determine the statistical parameters for the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.07
10 percentile	0.97
mean	3.72
90 percentile	18.64
maximum	373.00

7.6.5.3 St. Joseph Till

A total of 651 wells have been identified in areas where the St. Joseph Till outcrops at surface. Of these, 43 wells have been reported to be dry.

General information related to the quality of ground water is available for 526 wells. Approximately, 99% of these wells yield fresh water, and the remaining 1% yield either sulphurous or salty water.

A sample of 314 wells was selected to determine the statistical parameters for the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
mean	0.24
10 percentile	0.93
mean	5.96
90 percentile	44.74
maximum	447.00

7.6.6 Two Creeks Interstadial Deposits

This is a period of continued northward ice-marginal recession when most of southwestern Ontario and the southern parts of central Ontario became free of ice. Lake Iroquois occupied the Lake Ontario basin; Early Lake Erie occupied the Lake Erie basin; and Lake Algonquin occupied the southern parts of Lake Huron and Georgian Bay and extended eastward through the Lake Simcoe basin as far as Lake Scugog.

Shoreline deposits and glaciolacustrine sediments were left by Lake Iroquois to the north of Lake Ontario and by Lake Algonquin in the area between Lake Simcoe and Georgian Bay.

Four undifferentiated tills were deposited during this period due to minor oscillations of the ice margin (OGS Map 2556, Barnett, 1991):

- a sandy till, low in matrix carbonate content, which outcrops in small areas across the southern slopes of the Canadian Shield (Quaternary Unit 18);
- a sandy silt to silt till, which outcrops in many areas along the northern shores of Lake Ontario from Toronto to Belleville as well as in the Counties of Simcoe, Victoria, Leeds, Lanark, Dundas, and Stormont (Quaternary Unit 19);
- a sandy till, which outcrops in an area, extending from Victoria to Lennox-Addington Counties (Quaternary Unit 20); and
- a silty clay to silt till, which outcrops in a small area in Simcoe County (Quaternary Unit 21).

7.6.6.1 Quaternary Unit 18

A total of 17 wells have been identified in areas where Unit 18 outcrops at surface. The available information is insufficient to draw any meaningful conclusions about the characteristics of the wells within the unit.

7.6.6.2 Quaternary Unit 19

A total of 10,660 wells have been identified in areas where Unit 19 outcrops at surface. Of these, 115 wells have been reported to be dry.

General information related to the quality of ground water is available for 9,887 wells. Approximately, 99.5% of these wells yield fresh water, and the remaining 0.5% yield sulphurous, salty or mineral water.

A sample of 8,140 wells was selected to determine the statistical parameters of the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.09
10 percentile	1.32
mean	5.96
90 percentile	29.83
maximum	869.00

7.6.6.3 Quaternary Unit 20

A total of 190 wells have been identified in areas where Unit 20 outcrops at surface. Of these, 4 wells have been reported to be dry.

General information related to ground water quality is available for 177 wells. One well yield sulphurous water, while all the remaining wells yield fresh water.

A sample of 153 wells was selected to determine the statistical parameters of the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.36
10 percentile	1.42
mean	7.46
90 percentile	44.74
maximum	597.00

7.6.6.4 Quaternary Unit 21

A total of 142 wells have been identified in areas where Unit 21 outcrops at surface. Of these, 3 wells have been reported to be dry.

General information related to the quality of ground water is available 135 wells. Approximately, 98% of these wells yield fresh water, and the remaining 2% yield either salty or mineral water.

A sample of 113 wells was selected to determine the statistical parameters for the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.08
10 percentile	1.14
mean	5.26
90 percentile	25.94
maximum	89.50

7.6.7 Greatlakean Stade Deposits

Climatic conditions became cold again during this period of minor glacial advance. Evidence of such an advance exists in Wisconsin, but has not been documented in southern Ontario.

With the continued northward retreat of the ice margin, sea water invaded the valleys of the Ottawa and St. Lawrence Rivers to form the Champlain Sea. According to Barnett (1992), the general sequence of sediments, deposited within the Champlain Sea, includes:

- ice-marginal delta and subaqueous fan of sands and gravels,
- laminated silts and clays,
- clayey silts to clays containing marine fossils,
- laminated to varved silts and clays deposited at bottoms of the large deltas, which formed during regression of the Champlain sea, and
- nearshore and beach sands and gravels.

Sand and gravel deposits of glaciomarine origin occur in the Edwardsburg sand plain, which extends from Brockville and Cardinal in the south to Glouchester in the north. Similar deposits cover a large area, extending from Ottawa to Hucksburg, and they also form the Russell and Prescott sand plains.

During the Greatlakean Stade, glacial Lake Algonquin ended as the valleys of the Mattawa and Ottawa Rivers became ice-free about 10,400 to 10,000 years ago (Barnett, 1992).

7.6.8 Glaciofluvial, Glaciolacustrine, Glaciomarine and Marine Deposits

Throughout the Quaternary Period, sands and gravels of glaciofluvial, glaciolacustrine, glaciomarine or marine origins were deposited in various parts of southern Ontario. These deposits occur at different depths and locations. They can be small in size and capable of yielding enough water to satisfy the needs of a single home, or they can be large enough to satisfy the water needs of a village or a town. Table 4 gives a brief summary of these deposits in terms of age, stratigraphic unit, and origin.

Exposures of the sand and gravel deposits can be found at the surface over large areas in eastern and southwestern Ontario. In addition, the geologic logs of many water wells and test holes indicate that substantial amounts of sands and gravels occur at various depths in many parts of the province.

Singer (1981) described data collected from deep observation wells drilled in the Oak Ridges moraine. The data indicate that the moraine has a capping of sand and gravel with minor amounts of silt and till up to 100 m in thickness.

In a preliminary report on the stratigraphic drilling of Quaternary sediments in the Barrie area, Simcoe County, Barnett (1991) described the types of sediments occurring at depth in 8 boreholes. The logs of most of these boreholes show the presence of thick silt, sand and gravel deposits. For example, the log of borehole No. 90-7 reveals the following deposits:

Depth (m)	Soil/Rock Description
0.0 - 0.3	Fill
0.3 - 3.0	Sand
3.0 - 11.2	Silt
11.2 - 39.3	Sand

39.3 - 39.6	Gravel
39.6 - 69.2	Sand
69.2 - 71.3	Gravel
71.3 - 72.2	Silt and sand
72.2 - 81.4	Sand
81.4 - 84.9	Silt
84.9 - 86.8	Sand
86.8 - 92.1	Till
92.1 - 95.4	Bedrock

The origin of glaciofluvial deposits can be traced to the large volumes of meltwater that have been discharged by glaciers. Meltwater flowing from glaciers carry with it large amounts of debris of various grain sizes, and deposit them either in close proximity to the glaciers or farther away in stream channels, river deltas, glacier-fed lakes or the sea.

Glaciofluvial deposits are two types: Ice-contact stratified drift and outwash. Ice-contact deposits occur within or immediately adjacent to glaciers. Outwash, on the other hand, is deposited in rivers and streams beyond the glacier margin.

The make-up of the ice-contact deposits is highly variable both laterally and vertically. They consist mainly of discontinuous layers of sand and gravel with some silt, clay and till. Eskers, kames, kame terraces, interlobate moraines, and ice-marginal deltas occur mainly within the central and western parts of southern Ontario. These landforms consist of ice-contact deposits.

Outwash deposits are found mainly in southwestern Ontario. They consist of sands and gravels. Gravels are usually deposited in close proximity to the ice margin, whereas sands are found farther downstream. Deltas formed by meltwater streams at their entrances into glacier-fed lakes are also considered outwash deposits.

Glaciolacustrine deposits are sediments that have been carried by glacier meltwater and subsequently deposited in glacier-fed lakes. Rhythmites are the most common types of glaciolacustrine sediments. Along the shores and in the nearshore areas of lakes, sand and gravel beaches, spits and bars, and lake plains are formed.

Glaciomarine deposits are sediments that have been carried by glacier meltwater and subsequently deposited into a sea. The most common types of glaciomarine sediments are silty clays and clays. Due to their capacity to store and transmit large amounts of water, the sands and gravels of glaciofluvial, glaciolacustrine, glaciomarine or marine origins constitute good aquifers (Figure 19). Unfortunately, it is not possible in a regional study like this one to describe all these aquifers. Studies on watershed, subwatershed or site scales are required to identify the locations, spatial extent and specific characteristics of these aquifers.

In this report, the characteristics of wells, completed in areas where the sands, gravels, silts, and clays of glaciofluvial, glaciolacustrine, glaciomarine or marine origins outcrop at surface, have been described.

7.6.8.1 Ice-Contact Deposits

A total of 7,908 wells have been identified in areas where the ice-contact stratified drift deposits outcrop at surface. Of these 145 wells have been reported to be dry. General information related to the quality of ground water is available for 6,663 wells. Almost all these wells are reported to yield fresh water.

A sample of 5,628 wells was selected to determine the statistical parameters of the sample's specific capacity distribution. Figure A14 (Appendix II) shows a specific capacity-probability graph for the wells in the sample. The values plot approximately as a straight line, indicating that the sample has lognormal frequency distribution.

The minimum and maximum specific capacity values are 0.07 and 5,384.00 l/min/m, respectively. The 10 and 90 percentile values are 1.29 and 37.28 l/min/m, respectively, and the sample's geometric mean is 5.96 l/min/m.

7.6.8.2 Outwash Deposits

A total of 5,227 wells have been identified in areas where outwash deposits outcrop at surface. Of these, 62 wells have been reported to be dry. General information related to the quality of ground water is available for 4,689 wells. Approximately, 99% of these wells are reported to yield fresh water, and the remaining 1% yield either sulphurous or salty water.

A sample of 3,341 wells was selected to determine the statistical parameters for the sample's specific capacity distribution. Figure A14 (Appendix II) shows a specific capacity-probability graph for the wells in the sample.

The minimum and maximum specific capacity values are 0.12 and 4,823.00 l/min/m, respectively. The 10 and 90 percentile values are 1.86 and 74.57 l/min/m, respectively, and the sample's geometric mean is 10.65 l/min/m.

7.6.8.3 Sands and Gravels of Glaciolacustrine Origin

A total of 17,986 wells have been identified in areas where sands and gravels of glaciolacustrine origin outcrop at surface. Of these, 395 wells have been reported to be dry. General information about the quality of ground water is available for 16,053 wells. Over 99% of the wells yield fresh water, and the remaining wells yield sulphurous, salty or mineral water.

A sample of 8,025 wells was selected to determine the statistical parameters of the sample's specific capacity distribution. Figure A15 (Appendix II) shows a specific capacity-probability graph for the wells in the sample.

The minimum and maximum specific capacity values are 0.06 and 2,237.00 l/min/m, respectively. The 10 and 90 percentile values are 1.19 and 49.71 l/min/m, respectively, and the sample's geometric mean is 7.15 l/min/m.

7.6.8.4 Sands and Gravels of Glaciomarine and Marine Origins

A total of 489 wells have been identified in areas where sands and gravels of glaciomarine and marine origins outcrop at surface. Of these, 6 wells have been reported to be dry.

General information related to the quality of ground water is available for 478 wells. Approximately, 94% yield fresh water, and the remaining 6% yield either sulphurous or salty water.

A sample of 409 wells was selected to determine the statistical parameters of the sample's specific capacity distribution. Figure A15 (Appendix II) shows a specific capacity-probability graph for the wells in the sample.

The minimum and maximum specific capacity values are 0.12 and 426.00 l/min/m, respectively. The 10 and 90 percentile values are 2.66 and 49.71 l/min/m, respectively, and the sample's geometric mean is 9.94 l/min/m.

7.6.8.5 Silts and Clays of Glaciolacustrine Origin

A total of 8,682 wells have been identified in areas where silt and clay deposits of glaciolacustrine origin outcrop at surface. Of these 225 wells have been reported to be dry. General information related to ground water quality is available for 7,550 wells. Approximately, 98% of the wells yield fresh water, and the remaining 2% yield sulphurous, salty or mineral water.

A sample of 4,376 wells was selected to determine the statistical parameters of the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.06
10 percentile	1.12
mean	7.46
90 percentile	49.71
maximum	2386.00

7.6.8.6 Silts and Clays of Glaciomarine and Marine Origins

A total of 1,210 wells have been identified in areas where slit and clay deposits of glaciomarine and marine origins outcrop at surface. Of these, 14 wells have been reported to be dry.

General information related to ground water quality is available for 1,159 wells. Approximately, 89% of these wells yield fresh water, 5% yield salty water, 4% yield sulphurous water, and 2% yield mineral water.

A sample of 983 wells was selected to determine the statistical parameters of the sample's specific capacity distribution. The results are as follows:

Parameter	Specific capacity l/min/m
minimum	0.05
10 percentile	2.19
mean	10.65
90 percentile	45.89
maximum	1305.00

7.7 HOLOCENE (RECENT) DEPOSITS

The division between the Late Wisconsinan and the Holocene is somewhat arbitrary in Ontario as almost most of the northern parts of the province remained covered by ice 10,000 years ago. Southern Ontario, however, was free of ice and low level lakes existed in Georgian Bay, Lake Huron, Lake Erie and Lake Ontario.

During the Early Holocene, the Champlain Sea receded to east of Ottawa. Later, between 9,000 and 8,400 years ago, the flow of water from Early Lake Ontario through the St. Lawrence River became established.

As the land surface became free of ice, it began to rise isostatically. This affected the water levels in the Great Lakes basin, which began also to rise. Approximately, 5,000 years ago the Nipissing Great Lakes system came

into existence in the basins of Lakes Superior, Huron, Michigan and Georgian Bay. The Nipissing Great Lakes system left shoreline features in southern Ontario that are about 4 m above the southern Lake Huron shoreline. Eventually, the Nipissing Great Lakes system developed into the present-day Great Lakes system.

During the Holocene Epoch, deposits started to accumulate in various bogs and swamps, in the flood plains of rivers, and along the shorelines of lakes. Generally, these deposits are of limited importance as a source of ground water supplies.

8. GROUND WATER FLOW SYSTEMS

Ground water is subject to continuous movement, the rate of which is a function of the hydrogeologic characteristics of the material in which it moves, the existing hydraulic gradients and temperature. The existence of a three-dimensional, continuous ground water domain in a corresponding three-dimensional potential field has been established and developed by Hubert (1940), To'th (1962, 1963), and Freeze and Whitherspoon (1966, 1967).

The ground water hydraulic potential at a given point in this domain where the flow is at low velocity (Darcian) is given by:

$$H = g * z + (AP - P)/d \qquad (3)$$

where

H = hydraulic potential at a given point in the field,
g = gravity acceleration,
z = elevation at the point above an assumed datum,
AP = atmospheric pressure,
P = pressure at a given point, and
d = density of water.

The hydraulic head equals the hydraulic potential divided by the gravity acceleration and is measured in metres above a datum (usually mean sea level). Because the hydraulic head is obtained by dividing the hydraulic potential by a constant, it is a potential quantity itself and obeys the laws of potential theory. The hydraulic head, therefore, can be used as a potential function to describe the ground water flow system.

A number of piezometers can be inserted at different levels inside an observation well to provide hydraulic head readings at these levels. This is usually done if the well penetrates more than one aquifer. Many observation wells are needed to provide readings of the hydraulic heads at a given time in order to construct an accurate map of the hydraulic head distribution within a given aquifer. This can be a very expensive operation.

The data from the MOEE Water Well Observation Network is insufficient to provide the necessary information to delineate the ground water flow systems within the bedrock and overburden in southern Ontario. Data on static water levels from thousands of wells completed in the bedrock or the overburden are available. The water level data were obtained at different times and provide mean values of the hydraulic heads in various wells. Therefore, they cannot provide an exact picture of the hydraulic head configuration. Nevertheless, given the fact that the differences in hydraulic head readings are small within a well, these data can be used to provide a general picture of hydraulic head or static ground water level configuration on a regional scale.

Knowledge of the static water level configuration is of importance in ground water investigations as it indicates the direction and rate of ground water flow. Figure 20 shows the static ground water level configuration in the bedrock. The figure indicates that the ground water level configuration in the bedrock of southern Ontario is a subdued reflection of its surface topography.

Regional ground water divides coincide closely with the major basin topographic divides. Ground water appears to flow through river valleys towards the Great Lakes, and the Ottawa and St. Lawrence Rivers. In addition, the ground water basin of Lake Simcoe is well defined.

Within the Laurentian Highlands physiographic region, ground water flows radially from the north in Haliburton and Hastings Counties towards the Ottawa River, Lake Ontario and Georgian Bay. Within central Ontario, on the

other hand, a ground water divide runs through the Oak Ridges moraine diverting ground water flow northward to Lake Simcoe and southward to Lake Ontario.

Above the Niagara Escarpment, the Dundalk Dome directs ground water flow radially into Georgian Bay, Lake Huron, Lake St. Clair, Lake Erie, and Lake Ontario through a myriad of rivers and creeks. The Niagara Escarpment acts as a sink through which ground water flows under steep slopes towards Lake Ontario.

Figure 21 shows the static ground water level configuration in the overburden. The figure shows similar patterns to those described for the bedrock, but the patterns are more pronounced. Where the overburden is missing, the ground water flow systems in both the overburden and the bedrock become one system.

9. LONG-TERM GROUND WATER RECHARGE AND DISCHARGE

9.1 GROUND WATER AND THE HYDROLOGIC CYCLE

The hydrologic cycle is a concept that considers the processes of motion, loss and recharge of the Earth's water. Water that evaporates from the land and oceans is carried by the air masses and eventually precipitates either on land or oceans. Some of the precipitation that falls on land may be intercepted or transpired by plants and returned back to the atmosphere, some may runoff over the land surface to streams, and the remainder may infiltrate into the ground.

Some of the infiltrated water may be temporarily retained as soil moisture or moves laterally as interflow within the soil to the nearest stream. The remainder percolates deeper to the water table to be stored as ground water. The ground water, in turn, may be used by plants, or flows out as springs, or seeps into streams as baseflow, only to be eventually evaporated to the atmosphere to complete the hydrologic cycle (Gray, 1970).

From the foregoing it is clear that the hydrologic cycle is made up of several interrelated components (processes). Therefore, in order to study one of these components in detail, it is necessary to consider its relationships with all the other components.

9.2 SOIL MOISTURE AND GROUND WATER RECHARGE

The status of the soil moisture component is the decisive factor when it comes to ground water recharge. The zone of soil moisture is at critical juncture in the hydrologic cycle. From the initial impact of precipitation on the soil surface to the final drainage or evaporation of water from the soil, it presents many facets. Thus, the infiltration process, the storage of water within the soil profile, the transmission of water laterally as interflow or vertically as ground water recharge, the evaporation of the stored soil moisture or its utilization by plants, and the freezing-thawing cycles, all are facets of the role the soil moisture plays.

Precipitation is the primary source of water for the replenishment of soil moisture. Lateral transfer of water over the ground surface from topographic highs to lows, and the upward flow of water from the ground water zone to the unsaturated zone provide further sources of replenishment to soil moisture.

The primary mechanisms for soil moisture depletion are through evapotranspiration and gravity drainage. The magnitude of evapotranspiration is controlled by the soil moisture availability and the climatic conditions. Gravity drainage, on the other hand, occurs in response to pressure gradients either vertically or laterally. Whereas the lateral movement of the soil moisture generates interflow, its downward vertical movement contributes to ground water recharge (Singer, 1981).

9.3 TIMING OF GROUND WATER RECHARGE IN SOUTHERN ONTARIO

The process of ground water recharge is completely controlled by the status of soil moisture, provided that there is no gain to the ground water storage from outside areas. There is a confusion in the minds of many people regarding ground water recharge. The impression some people have is that ground water recharge is limited to certain areas. Except in river and stream valleys that constitute the main ground water discharge zones, ground water recharge occurs almost everywhere. The rate of ground water recharge, however, is high in certain areas and the identification of such areas is, therefore, important for the appropriate management of the ground water resources.

Measurements of static water level variations and precipitation at observation wells are good means to determine the periods of ground water recharge. When discussing ground water recharge, it is important to keep in mind that the ground water storage is continually being depleted by discharge to streams. Therefore, when the static water level in an observation well remains steady the ground water recharge and discharge are equal. A rise in the static level indicates that recharge is more than discharge, a fall means the reverse is true.

Recharge to ground water occurs at a maximum rate when the soil is in a state of complete saturation and diminishes when the soil is at the wet limit (field capacity). In southern Ontario, this condition is met mainly during the snowmelt and spring rainfall events, which usually extends from mid March through April and early May (Figures 22 and 23).

During this period temperatures start to rise, signalling the arrival of spring. The soil moisture is close to saturation and evapotranspiration is low. The snow pack is sharply depleting until it vanishes completely. A vast amount of liquid water, produced by melting snow and rainfall events, is suddenly available. Part of this water generates high flows and floods. The remaining water infiltrates through the soil and then percolates to the ground water storage. This is the period of major ground water recharge in southern Ontario when the water table reaches a maximum height and the ground water storage is at its peak.

Rainfall events that occur during the period from late October to early December also contribute to ground water recharge. During this period, the temperature is declining, the growing season is finished, evapotranspiration is low, and soil moisture is being restored to saturation level by precipitation that is mostly in the form of rain. The net result is recharge to ground water and rising water tables. Finally, some recharge to ground water could take place during winter warm spells (Figures 22 and 23).

During the summer and early fall, the soil moisture is utilized mainly by plants through evapotranspiration and a state of soil moisture deficiency usually prevails. Therefore, most of the infiltrated water from the rain, during this period, is used to satisfy this deficiency with little or no water left to recharge the ground water. As a result, ground water levels steadily decline except during heavy rainfall events (Figure 22 and 23).

9.4 QUANTITATIVE ASSESSMENT OF LONG-TERM GROUND WATER DISCHARGE AND RECHARGE

It is generally recognized that streamflow consists of the following three components:

- i direct runoff, which is that part of precipitation that flows over the land surface to the streams;
- ii interflow, which is that part of precipitation that flows part of the way underground, but does not become part of the ground water regime; and
- iii baseflow, which is that part of the precipitation that reaches the streams as natural ground water discharge, after being a part of the ground water regime.

One way to estimate the ground water discharge is to separate the streamflow into different components. Unfortunately, the principles of separating the streamflow into components are not well developed, and in the case of complex streamflow events streamflow separation appears to be somewhat arbitrary. It is believed, however, that if a certain method of streamflow separation is followed consistently, the same error will be committed systematically and, therefore, useful results can be obtained for comparative purposes.

For the purpose of this report, a Streamflow Separation Program was developed. The Program separates streamflow into two components: a surface runoff component consisting of direct runoff and interflow, and a baseflow component. The Program allows for the processing of a large amount of data in a very short time and ensures consistency in the application of the technique.

Six parameters are used in the Program. The first parameter is used to detect the beginning of an event; the second to determine the event period; the third to detect the peak flow; the fourth to determine the value of the ground water component under the peak; the fifth to determine the relative event limits; and the sixth to determine the absolute event limit.

Data from 33 gauging stations located in small watersheds in southern Ontario were selected to separate the streamflows. Care was taken to ensure that the size of each selected watershed is less than 200 km^2, that streamflows at all the gauging stations are natural flows, and that the period of record at each station is long enough to allow for the estimation of long-term means.

All the selected streamflow gauging stations have more that 8 years of daily streamflow records. The available records were processed using the Streamflow Separation Program. Table 5 gives the names and numbers of the gauging stations, the period of records, and the drainage area.

Table 6 gives the long-term means of monthly and annual ground water discharge, which were calculated for the 33 gauging stations. An examination of Table 6 reveals that the long-term monthly means are highest during the months of March, April and May; they decrease steadily during the period June-October and start to recover during November and December. This pattern is similar to the pattern of ground water level fluctuations shown on Figures 22 and 23.

The long-term means of annual ground water discharge, calculated for the 33 stations, range from 83.34 to 284.88 mm. Given that the records at these stations is long and that the change in soil moisture storage approaches zero over such long periods of records, it is possible to assume that the long-term means of monthly and annual ground water discharge, calculated for the 33 gauging stations, are equal to the long-term means of monthly and annual ground water recharge.

10. GROUND WATER QUALITY

The chemical composition of ground water is an important consideration in any hydrogeologic study. The suitability of the ground water for use by agriculture, commerce, industry or for drinking purposes can be assessed by a study of its chemistry.

The Provincial Drinking Water Objectives (PDWO) specify the limits for a number of common chemical and physical parameters that apply to all water supply systems that provide water for domestic purposes and serves more than five private residences or are capable of supplying more than 50,000 litres of water a day (MOEE, 1994). A water supply system includes the works and auxiliaries for collecting, treating, storing and distributing water from the source of supply to the consumers. Some PDWOs are aesthetic or health-related, while others are operational guidelines established for parameters that need to be controlled to ensure efficient treatment of water.

The following are the PDWOs for a number of parameters that are routinely found in natural ground water:

Parameter	Objective (mg/l)	Type of Objective
Sodium	200	Aesthetic
Iron	0.3	Aesthetic
Chloride	250	Aesthetic
Sulphate	250	Aesthetic
Nitrate as Nitrogen	10	Health-related
Total Dissolved Solids	500	Aesthetic
Hardness (as $CaCO_3$)	80 - 100	Operational Guideline

Hardness is a common characteristic of ground water in most areas of southern Ontario. High hardness is a nuisance resulting in a scale formation on kettles, it prevents soap from lathering, and it can result in a dingy laundry. The PDWO for hardness is an operational guideline. In terms of water treatment, hardness is classified as follows:

Hardness Range (mg/l as $CaCO_3$)	Water Treatment
80 - 100	Optimal
100 - 200	Acceptable
200 - 500	Tolerable
> 500	Unacceptable

Another classification scheme for hardness is as follows:

Hardness Range mg/l of $CaCO_3$	Type of water
10 - 60	soft
61 - 120	moderately hard
121 - 180	hard
> 180	very hard

Natural ground waters have often superior water quality, which makes them highly attractive as sources of drinking water supplies. Unfortunately, certain natural ground waters do not meet always all the limits set under the PDWOs. Some natural ground waters have high levels of total dissolved solids, hardness, sulphate, hydrogen sulphide or iron. Home treatment devices are available to treat these problems.

Natural ground waters usually have very low levels of nitrate and are free from bacteria. The detection of high levels of nitrate or any amounts of faecal or total coliform bacteria in a water sample, collected from a well, is an indication that the well has been contaminated. Most water well contamination is the result of poor location, inferior construction methods or inadequate maintenance.

The well record includes information related to the kind of ground water that was encountered in the well in terms of being fresh, salty, sulphurous, or containing iron or gas. This information is submitted to MOEE by the well driller as part of the well record. Usually, the driller visually examines a water sample taken from the well for clarity, then smells and tastes the water, and enters his/her observations into the well record.

The information provided by the well driller is very useful especially when the water from the well tastes salty or smells like a rotten egg, which indicates the presence of sodium chloride or hydrogen sulphide in the water. This information, however, is subjective and is inadequate for determining the suitability of ground water for drinking purposes.

Throughout the years, water quality analyses were carried out on many municipal and private wells. A concerted effort was made during this study to assemble all the available chemical data for further evaluation.

In order to assess the quality of ground water within various bedrock and overburden units and determine the types of ground water in these units, a computer program called: "Durov Water Quality Analyzer" was used (Durov, 1948).

Water quality data in mg/l are converted by the program into equivalents per million (EPM) and percent EPM values. The EPM values are used to calculate the ion balance and determine the percent ion balance. The percent EPM values, on the other hand, are used to determine the dominant ions in each sample and generate a water type table. The percent EPM values can then be plotted on a trilinear diagram, which shows the dominant cations and anions for all the samples.

10.1 GROUND WATER QUALITY IN THE BEDROCK

General information related to the quality of ground water is available for 129,797 bedrock wells. The records indicate that the majority of bedrock wells yield fresh water. A considerable number of wells, however, are reported to have some natural water quality problems. Figure 24 shows the locations of bedrock wells that have been reported to yield salty, sulphurous or mineral water as well as the locations of wells that yield water containing gas.

Figure 24 indicates that bedrock wells that yield sulphurous water are concentrated in three bands in southern Ontario. The first band extends from the Ottawa River in the north to the St. Lawrence River in the south. The second band extends along the south-western slopes of the Canadian Shield from Addington and Prince Edward Counties to Georgian Bay. The third band extends from the Niagara River in the east to Essex County in the west.

Bedrock wells that yield salty water are concentrated to the south of the Ottawa River, and can be found in Addington, Prince Edward, Halton, Peel, Kent, Lambton, and Essex counties. Most of the bedrock wells, which yield water containing gas, are located in Kent and Lambton counties.

The results of 533 chemical analyses for water samples collected from bedrock wells are available. Appendix III lists these results and gives the well numbers or the geographic coordinates of the wells.

Figures 25, 26, 27, 28, and 29 show the percentages of samples exceeding the PDWO objectives for sodium, iron, chloride, sulphate, and total dissolved solids, respectively. Figure 30 provides a comparison among the various bedrock units in terms of minimum, maximum and mean levels of hardness.

10.1.1 Precambrian Hydrogeologic Unit

The well records indicate that the majority of the wells in Precambrian rocks provide fresh water supplies. A very small number of records, however, show some natural water quality problems; 19 wells are reported to yield salty water, 24 sulphurous water and 13 mineral water.

The results of 8 chemical analyses, for water samples taken from wells completed in Precambrian rocks, indicate that the natural ground water quality in Precambrian rocks is generally good.

The mean concentration of total dissolved solids for the samples is 412.33 mg/l, and the water hardness ranges from acceptable to unacceptable. Further, 43 % of the samples have iron levels above the PDWO, and 25% of the samples have sulphate levels above the PDWO.

Table 9 gives the results of the water type analysis (Durov analysis) for various bedrock hydrogeologic units. The analysis was conducted on three samples obtained from wells completed in the precambrian hydrogeologic unit. The results of the analysis indicate that two samples are of calcium-bicarbonate type and one sample is of bicarbonate type.

10.1.2 Nepean-March-Oxford Hydrogeologic Unit

General information related to the quality of ground water within the Nepean-March-Oxford hydrogeologic unit is available for 17,390 wells. The majority of these wells yield fresh water. A few of the wells, however, yield sulphurous water (193 wells) or salty water (33 wells).

The results of 33 chemical analyses, for water samples taken from wells completed in the Nepean-March-Oxford hydrogeologic unit, indicate that the natural ground water quality in the unit is generally good. The concentration of total dissolved solids ranges from 486.28 to 1,380.00 mg/l, and 28% of the samples have levels above the PDWO. Water hardness ranges from optimal to unacceptable.

Iron concentrations are generally low. However, 8 samples have iron concentrations above the PDWO and 3 samples have concentrations in excess of 5.0 mg/l.

The nitrate concentrations for the majority of the samples are much below the PDWO. Nevertheless, some samples show very high nitrate levels. This is an indication that human activities are contributing significant nitrate loadings to the ground water within this hydrogeologic unit.

Water type analysis was conducted on 28 samples. The results of the analysis indicate that most of the samples are of bicarbonate type or of calcium-bicarbonate type.

10.1.3 Rockcliffe Hydrogeologic Unit

General information related to the quality of ground water in the unit is available for 2,089 wells. Of these wells, 97% yield fresh water, 2% yield sulphurous water and 1% yield salty water.

The results of one chemical analysis, for a water sample taken from a well completed in the Rockcliffe hydrogeologic unit, is available. The results indicate that the ground water quality is good. Water hardness, however, is only tolerable. The water is of bicarbonate type.

10.1.4 Ottawa Group Hydrogeologic Unit

General information related to the quality of ground water in the Ottawa Group hydrogeologic unit is available for 10,048 wells. Approximately, 91% of these wells yield fresh water, 5% yield sulphurous water and 4% yield either salty or mineral water.

The results of 39 chemical analyses, for water samples taken from wells completed in the Ottawa Group hydrogeologic unit, are available. Although the water quality of the samples is generally suitable for domestic use, some samples show poor water quality.

The concentrations of total dissolved solids are high with 62% of the samples exceeding the PDWO. Water hardness ranges from optimal to unacceptable with a mean concentration of 277.92 mg/l.

Many samples show excessive levels of iron, sodium, chloride and sulphate. The PDWOs are exceeded in 45% of the samples with respect to iron, in 21% of the samples with respect to sodium. in 10% of the samples with respect to chloride, and in 3% of the samples with respect to sulphate. In addition, a number of samples show high nitrate levels, indicating that some nitrate loadings to this hydrogeologic unit is taking place as a result of human activities.

Water type analysis was conducted on 32 samples. The analysis indicates that the majority 41% of the samples are of calcium-bicarbonate type (41%), bicarbonate type (31%) or sodium-potassium-bicarbonate type (16%).

10.1.5 Simcoe Group Hydrogeologic Unit

General information related to the quality of ground water in the Simcoe Group hydrogeologic unit is available for 28,033 wells. Approximately, 78% of the wells yield fresh water, 5.2% yield sulphurous water and 1.42% yield salty or mineral water. No data are available for the remaining 15.38% of the wells.

The results of 38 chemical analyses, for water samples taken from wells completed in the Simcoe Group hydrogeologic unit, are available. These results indicate that the suitability of ground water within this unit for domestic use ranges from poor to good.

The mean concentration of total dissolved solids is 647.00 mg/l with 42% of the samples showing levels above the PDWO. Water hardness ranges from optimal to unacceptable with a mean concentration of 285.89 mg/l. Some samples also show levels above the PDWOs for iron (37%), sodium (15%), chloride (11%) and sulphate (11%).

Water type analysis was conducted for 33 samples. The results indicate that the majority of the samples are of calcium-bicarbonate type (36%), bicarbonate type (21%), sodium-potassium-bicarbonate type (15%) or sodium-potassium-sulphate-nitrate type (12%).

10.1.6 Billings-Carlsbad-Queenston Hydrogeologic Unit

General information related to the water quality of ground water in the Billings-Carlsbad-Queenston hydrogeologic unit are available for 1,058 wells. Approximately, 80% of these wells yield fresh water, 14% yield sulphurous water and 6% yield either salty or mineral water.

The results of 10 chemical analyses, for water samples taken from wells completed in the unit, indicate that the ground water quality is generally poor. The concentrations of total dissolved solids exceed the PDWO in 70% of the samples with a mean concentration of 947.10 mg/l. Water hardness ranges from optimal to unacceptable.

The PDWO for sodium is exceeded in 50% of the samples, and the PDWO for chloride is exceeded in 30% of the samples. High sodium concentrations in ground water are commonly associated with shales. Sodium occurs naturally in shales and the ion exchange process results in the replacement of calcium with sodium in ground water (Sibul et al, 1977). The mean concentration of calcium in the water samples is in fact low at 49.00 mg/l.

Although the concentrations of iron are generally low, 3 samples have iron levels exceeding the PDWO. The results of the chemical analyses show no indication of nitrate contamination.

Water type analysis was conducted for the 10 samples. The analysis indicates that the majority of the samples are of sodium-potassium-chloride type (30%), sodium-potassium-bicarbonate type (20%) or bicarbonate type (20%).

10.1.7 Blue Mountain-Georgian Bay Hydrogeologic Unit

General information related to the quality of ground water encountered in the unit is available for 1,678 wells. Of these wells, 87% yield fresh water, 8% yield salty water, and the remaining 5% yield sulphurous or mineral water.

The results of 13 chemical analyses for water samples, taken from wells completed in the Georgian Bay-Blue Mountain hydrogeologic unit, are available. Although the quality of ground water is generally suitable for domestic use, some samples show poor water quality.

The concentrations of total dissolved solids exceed the PDWO in 71 % of the samples and the mean concentration is 686.00 mg/l. Water hardness ranges from optimal to unacceptable with a mean concentration of 262.69 mg/l.

Many samples show excessive levels of sodium and chloride, which is reflected by their mean concentrations of 109.04 mg/l and 137.31 mg/l, respectively. The PDWOs for sodium were exceeded in 3 samples and the PDWOs for chloride were exceeded in 2 samples. Iron concentrations are generally below the PDWO, however, 4 samples have levels above the objective.

Water type analysis, which was conducted on 12 samples, indicates that the majority of the samples are of bicarbonate type (33%), sodium-potassium-chloride type (25%) or sodium-potassium-bicarbonate type (17%).

10.1.8 Queenston Hydrogeologic Unit

General information about the quality of ground water in the unit is available for 3,330 wells. Of these wells, 92% yield fresh water, 5% yield salty water, and 3% yield either sulphurous or mineral water.

The results of 12 chemical analyses for water samples, taken from wells drilled in the Queenston hydrogeologic unit, are available. The water quality of the samples is highly variable, ranging from poor to good.

The total dissolved solids concentrations exceed the PDWO in five of eight samples. Water hardness ranges from acceptable to unacceptable with a mean concentration of 472.00 mg/l.

Many samples show excessive levels of sodium and chloride, which is reflected by their mean concentrations of 88.00 mg/l and 123.00 mg/l, respectively. Sulphate concentrations range from 18.00 mg/l to 1,220.00 mg/l with the mean concentration at 251.00 mg/l. Four of the 12 samples exceeded the PDWO for sulphate and one of five samples exceeds the PDWO for iron.

Water type analysis was conducted on 10 samples. The analysis indicates that three samples are of calcium-bicarbonate type, two samples are of calcium-sulphate-nitrate type, one sample is of calcium type, one sample is of sodium-potassium-chloride type, and two samples have no dominant type.

10.1.9 Clinton Group -Cataract Group Hydrogeologic Units

The results of three chemical analyses are available for three wells completed either in the Cataract Group or the Clinton Group hydrogeologic units. The results indicate that the ground water quality is within the PDWOs for sodium, chloride, sulphate and total dissolved solids and that water hardness is tolerable. One sample however, shows iron levels above the PDWO. The water in two samples is of calcium-bicarbonate type and in one sample is of bicarbonate type.

10.1.10 Amabel-Lockport-Guelph Hydrogeologic Unit

General information related to the quality of ground water is available for 22,812 wells. Approximately, 96% of the wells yield fresh water, and the remaining 4% of the wells yield salty, sulphurous or mineral water.

The results of 96 chemical analyses for water samples, taken from wells drilled in the Amabel Formation, are available. Although the quality of ground water is generally suitable for domestic use, some samples show poor water quality.

The concentrations of total dissolved solids exceed the PDWO in 21% of the samples. Water hardness ranges from acceptable to unacceptable with a mean concentration of 384.92 mg/l.

Iron concentrations exceed the PDWO in 37% of the samples. Sulphate concentrations range from 1.00 mg/l to 1,300.00 mg/l, and 6% of the samples exceed the PDWO for sulphate. The concentrations of sodium and chloride, however, are generally low, which is reflected by their mean concentrations of 16.00 mg/l and 28.00 mg/l, respectively.

In addition, 11% of the samples show high nitrate levels (>5.00 mg/l). This indicates that some nitrate loadings to ground water in this unit are occurring as a result of human activities.

Water type analysis was conducted on 69 water samples. The analysis indicates that 78% of the samples are of calcium-bicarbonate type, 10% are of bicarbonate type, 9% are of calcium-sulphate-nitrate type, and 3% show no dominant type.

The results of 48 chemical analyses of water samples, taken from wells drilled in the Guelph Formation, are available. Although the quality of ground water is generally suitable for domestic use, many samples show poor water quality.

The concentrations of total dissolved solids exceed the PDWO in 35% of the samples. Water hardness ranges from optimal to unacceptable with a mean concentration of 469.44 mg/l.

Iron concentrations exceed the PDWO in 60% of the samples. Sulphate concentrations range from 2.00 mg/l to 1,600.00 mg/l and 23% of the samples exceed the PDWO. As is the case with the Amabel Formation, the concentrations of sodium and chloride are generally low, which is reflected by their mean concentrations of 36.00 mg/l and 53.00 mg/l, respectively.

Again, 11% of the samples show high nitrate levels (>5 mg/l). This indicates that some nitrate loadings to ground water in this unit are occurring as a result of human activities.

Water type analysis was conducted on 43 samples. The results indicate that 37% of the water samples are of calcium-bicarbonate type, 26% are of bicarbonate type, and 16% are of calcium-sulphate-nitrate type. The remaining 21% of the samples are of sulphate-nitrate type, calcium type, sodium-potassium type or have no dominant type.

No chemical analyses are available for water samples from the Lockport Formation.

10.1.11 Salina Hydrogeologic Unit

General information is available for 3,582 of wells completed in the Salina Formation. Approximately, 90% of the wells yield fresh water, 6% yield sulphurous water, and the remaining 4% yield either salty or mineral water.

The results of 63 chemical analyses for water samples, taken from wells drilled in the Salina hydrogeologic unit, are available. Many of these samples show poor water quality. This is most likely due to the presence of anhydrite and gypsum in the Salina Formation.

The concentration of total dissolved solids exceed the PDWO in 69% of the samples. Water hardness ranges from acceptable to unacceptable with a mean concentration of 1,110.53 mg/l.

Sulphate concentrations in the samples range from 4.00 mg/l to 2,570.00 mg/l, and the mean concentration is 975.00 mg/l. The PDWO for sulphate is exceeded in 65% of the samples and sulphate concentrations above 1,000.00 mg/l have been found in 49% of the samples.

Iron concentrations exceeded the PDWO in 68% of the samples. The concentrations of sodium and chloride, on the other hand, are generally low, which is reflected by their mean concentrations of 68.00 mg/l and 38.00 mg/l, respectively. Nevertheless, the PDWO for sodium is exceeded in 11% of the samples.

Also, 9% of the samples show high nitrate levels (>5.00 mg/l). This indicates that some nitrate loadings to ground water in this hydrogeologic unit are occurring as a result of human activities.

Water type analysis was conducted on 54 water samples. The results, indicate that 61% of the water samples are of calcium-sulphate-nitrate type, 22% are of calcium-bicarbonate type, and 7% are of sulphate-nitrate type. The remaining 10% of the samples are of bicarbonate type, calcium type or have no dominant type.

10.1.12 Bass Island Hydrogeologic Unit

General information related to the quality of ground water in the Bass Island hydrogeologic unit is available for 860 wells. Of these wells, 95% yield fresh water, 3% yield sulphurous water, and 2% yield mineral water.

The results of 19 chemical analyses for water samples, taken from wells drilled in the Bass Island hydrogeologic unit, are available. Many of these samples show poor water quality.

The concentration of total dissolved solids exceed the PDWO in 47% of the samples. Water hardness ranges from optimal to unacceptable with a mean concentration of 788.26 mg/l.

Sulphate concentrations in the samples range from 5.00 mg/l to 2,197.00 mg/l, and the PDWO for sulphate is exceeded in 35% of the samples. Further, sulphate concentrations above 1,000.00 mg/l have been found in 24% of the samples.

Iron concentrations exceed the PDWO in 47% of the samples. However, the concentrations of sodium and chloride are generally low, which is reflected by their mean concentrations of 32.00 mg/l and 14.00 mg/l, respectively.

In addition, 14% of the samples show high nitrate levels (>5.00 mg/l). This indicates that some nitrate loadings to ground water in this hydrogeologic unit are occurring as a result of human activities.

Water type analysis was conducted on 12 samples. The results indicate that 42% of the samples are of calcium-sulphate-nitrate type, and 33% are of calcium-bicarbonate type. The remaining samples are of bicarbonate type, calcium type or sodium-potassium-bicarbonate type.

10.1.13 Bois Blanc Hydrogeologic Unit

General information related to the quality of ground water is available for 1,232 wells. Approximately, 93% of these wells yield fresh water, 6% yield sulphurous water, and the remaining 1% yield salty or mineral water.

The results of 23 chemical analyses for water samples, taken from wells drilled in the Bois Blanc hydrogeologic unit, are available. Many of these samples show poor water quality.

The concentrations of total dissolved solids exceed the PDWO in 48% of the samples. Water hardness ranges from acceptable to unacceptable with a mean concentration of 599.93 mg/l.

Sulphate concentrations range from 4.00 mg/l to 1,875.00 mg/l, and the PDWO for sulphate is exceeded in 32% of the samples. Further, sulphate concentrations above 1,000.00 mg/l have been found in 24% of the samples.

Iron concentrations exceed the PDWO in 65% of the samples. However, the concentrations of sodium and chloride are generally low, which is reflected by their mean concentrations of 32.00 mg/l and 15.00 mg/l, respectively.

Two samples show high nitrate levels (>5.00 mg/l). This indicates that some nitrate loadings to ground water in this hydrogeologic unit are occurring as a result of human activities.

Water type analysis was conducted on 17 samples. The results indicate that 29% of the samples are of bicarbonate type, 24% are of calcium-bicarbonate type, 24% are of the calcium-sulphate-nitrate type, and 12% are of sulphate-nitrate type. The remaining samples are of magnesium-bicarbonate type or calcium type.

10.1.14 Detroit River Group Hydrogeologic Unit

General information related to ground water in this hydrogeologic unit is available for 7,573 wells. Approximately, 90% of these wells yield fresh water, 4% yield sulphurous water, and the remaining 6% yield salty water or water containing gas.

The results of 77 chemical analyses for water samples, taken from wells drilled in the Detroit River Group hydrogeologic unit, are available. Many of these samples show poor water quality.

The concentrations of total dissolved solids exceed the PDWO in 50% of the samples. Water hardness ranges from optimal to unacceptable with a mean concentration of 578.45 mg/l.

Sulphate concentrations range from 0.40 mg/l to 3,100.00 mg/l, and the PDWO for sulphate is exceeded in 22% of the samples. Sulphate concentrations above 1,000.00 mg/l have been found in 6 of the samples. Also, many samples show elevated concentrations of sodium and chloride, which is reflected by their mean concentrations of 73.00 mg/l and 112.00 mg/l, respectively.

iron concentrations exceed the PDWO in 64% of the samples. In addition, 4 samples show high nitrate levels (>5.00 mg/l), which indicates that some nitrate loadings to ground water in this hydrogeologic unit are occurring as a result of human activities.

Water type analysis was conducted on 40 water samples. The results indicate that 43% of the samples are of calcium-bicarbonate type, 23% are of bicarbonate type, 10% are of magnesium-sulphate-nitrate type, and 10% are of magnesium-bicarbonate type. The remaining samples are of calcium type, sulphate-nitrate type, calcium-sulphate-nitrate type or sodium-potassium-bicarbonate type.

10.1.15 Dundee Hydrogeologic Unit

General information related to the quality of ground water in the Dundee hydrogeologic unit is available for 4,664 wells. Approximately, 79% of these wells yield fresh water, 19% yield sulphurous water, and the remaining 2% yield either salty or mineral water.

The results of 78 chemical analyses of water samples, taken from wells drilled in the Dundee hydrogeologic unit, are available. Many of these samples show poor water quality.

The concentration of total dissolved solids concentrations exceed the PDWO in 45% of the samples. Water hardness ranges from optimal to unacceptable with a mean concentration of 378.22 mg/l.

Sulphate concentrations in the samples range from 1.00 mg/l to 1,430.00 mg/l, and the PDWO for sulphate is exceeded in 13% of the samples. Many samples also show elevated concentrations of sodium and chloride, which is reflected by their mean concentrations of 124.00 mg/l and 175.00 mg/l, respectively.

Iron concentrations exceed the PDWO in 59% of the samples. In addition, three out of 29 samples show high nitrate levels (>5.00 mg/l), which indicates that some nitrate loadings to ground water in this hydrogeologic unit are occurring as a result of human activities.

Water type analysis was conducted on 27 water samples. The results indicate that 37% of the samples are of bicarbonate type, 15% are of sodium-potassium-bicarbonate type, and 11% are of calcium-bicarbonate water type. The remaining 37% of the samples are comprised of 8 different water types, indicating that water quality within this hydrogeologic unit is highly variable.

10.1.16 Hamilton Group Hydrogeologic Unit

General information related to the quality of ground water in the Hamilton Group hydrogeologic unit is available for 1,364 wells. Approximately, 81% of these wells yield fresh water, 13% yield sulphurous water, and the remaining 6% yield salty water or water containing gas.

The results of 11 chemical analyses for water samples, taken from wells drilled in the Hamilton Group hydrogeologic unit, are available. Many of the samples show poor water quality.

The concentrations of total dissolved solids exceed the PDWO in 75% of the samples. Water hardness ranges from optimal to unacceptable with a mean concentration of 197.80 mg/l.

Many samples show elevated concentrations of sodium and chloride, which is reflected by their mean concentrations of 161.25 mg/l and 350.40 mg/l, respectively. Sulphate concentrations in the samples are low, ranging from 1.00 mg/l to 85.00 mg/l. Iron concentrations, on the other hand, exceed the PDWO in 64% of the samples.

Water type analysis was conducted on three water samples. The results indicate that one sample is of calcium-bicarbonate type, one sample is of sodium-potassium-chloride type, and one sample is of sodium-potassium-bicarbonate type.

10.1.17 Kettle Point Hydrogeologic Unit

General information related to the quality of ground water in this hydrogeologic unit is available for 4,006 wells. Approximately, 88% of the wells yield fresh water, 7% yield sulphurous water, and the remaining 5% yield salty or mineral water.

The results of 22 chemical analyses for water samples, taken from wells drilled in the Kettle Point hydrogeologic unit, are available. Many of these samples show poor water quality.

The concentration of total dissolved solids exceed the PDWO in 60% of the samples. Water hardness ranges from optimal to tolerable with a mean concentration of 99.00 mg/l.

Many samples show elevated concentrations of sodium and chloride, which is reflected by their mean concentrations of 478.67 mg/l and 261.82 mg/l, respectively. The PDWO for sodium is exceeded in 33% of the samples, while the PDWO for chloride is exceeded in 25% of the samples.

Sulphate concentrations are low, ranging from 1.00 mg/l to 82.00 mg/l. Iron concentrations, on the other hand, exceed the PDWO in 76% of the samples.

Water type analysis was conducted on six samples. In the absence of any nitrate data, a conservative nitrate value of 0.50 mg/l was substituted. The analysis indicated that three of the samples are of sodium-potassium-bicarbonate type, two are of sodium-potassium-chloride type, and one is of calcium-bicarbonate type.

10.2 GROUND WATER QUALITY IN THE OVERBURDEN

General information related to the quality of ground water encountered in various overburden deposits is available for 77,713 wells. General information related to the quality of ground water in the overburden is available for 77,713 water wells. Approximately, 98.7% of these wells have been reported to yield fresh water, and the remaining 1.3% yield sulphurous, salty or mineral water or water containing gas.

Figure 31 shows the locations of overburden wells that have been reported to have water quality problems. Most of wells that have been reported to yield sulphurous water are located in the Counties of Essex, Middlesex, Simcoe, Elgin, Lambton, Ottawa-Carleton, Norfolk, Welland (Niagara), Oxford and Lincoln (Niagara).

Most of the wells that have been reported to yield salty water are located in the Counties of Russell, Prescott, Ottawa-Carleton and Kent. Most of the wells that have been reported to yield mineral water are located in the Counties of Simcoe, Northumberland, Dufferin and York. Finally, most of the wells that have been reported to yield water containing gas are located in Kent County.

The results of 522 chemical analyses are available. These analyses are for water samples collected from wells where various overburden deposits outcrop at surface. Appendix IV tabulates these results by well number or geographic coordinates.

Unfortunately, it is not possible to ascribe the quality of a water sample, collected from of a well completed in an area where a given overburden deposit outcrops at surface, to that particular unit. This is due to the fact that the well may penetrate a number of overburden units and it is not possible to determine which unit is contributing most of the water in the well.

The situation, on the other hand, is different in the case of bedrock wells. Logic dictates that the drilling process of a well would not have proceeded into the bedrock unless that was absolutely necessary, either because of lack of water within the overlying overburden deposits or because the amount of water found was totally inadequate. Although one has to allow for the possibility of some water mixing, the quality of water in a bedrock well represents, by and large, the quality of ground water within the bedrock hydrogeologic unit, which the well taps.

Faced with these difficulties, the description of ground water quality within the overburden will be given in terms of water quality parameters and water type rather than in terms of specific overburden units. The parameters that will be considered are: sodium, iron, chloride, sulphate, nitrate, total hardness, and total dissolved solids.

10.2.1 Sodium

The concentrations of sodium range from less than 1.60 to 1,430.00 mg/l. The majority of samples have concentrations of sodium much below the PDWO. However, 33% of the samples, collected from wells where the Tavistock Till outcrops at the surface, have sodium concentrations above the PDWO. Some, if not all, the exceedances of the PDWO for sodium could be the result of road deicing.

10.2.2 Iron

The concentrations of iron range from less than 0.01 to 94.00 mg/l. The samples, collected from the three wells, completed in areas where Quaternary Unit 21 (undifferentiated silty clay to silt till) outcrops at surface, have concentrations of iron above the PDWO. Further, a percentage (8% to 75%) of the samples, collected from wells completed in all the other overburden deposits that outcrop at the surface, exceeds the PDWO for iron.

10.2.3 Chloride

The concentrations of chloride range from 0.10 to 2,424.00 mg/l. The majority of the samples are much below the PDWO. However, about 25% of the samples, collected from wells completed in areas where the Tavistock Till outcrops at the surface, have chloride concentrations above the PDWO. Some, if not all, the exceedances of the PDWO for chloride could be the result of road deicing.

10.2.4 Nitrate

The concentrations of nitrate range from less than 0.02 to 66 mg/l. The majority of the samples are much below the PDWO for nitrate. Nevertheless, about 40% of the samples, collected from wells completed in areas where the Mornington Till outcrops at the surface, have nitrate concentrations above the PDWO. The same is true for the samples collected from wells completed in areas where the sands and gravels of glaciomarine and marine origins outcrop at the surface. All the exceedances of the PDWO for nitrate are believed to be the result of human activities.

10.2.5 Sulphate

The concentrations of sulphate range from less than less than 0.01 mg/l, in samples collected from wells completed in areas where the Port Stanley Till outcrops at the surface, to 2,100.00 mg/l in samples collected from wells completed in areas where the sands and gravels of glaciolacustrine origin outcrop at the surface.

Most of the samples have sulphate concentrations below the PDWO. Nevertheless, 29% of the samples, collected from wells completed in areas where the silts and clays of glaciolacustrine origin outcrop at the surface, exceed the PDWO for sulphate.

10.2.6 Hardness

Water hardness range from 40.00 to 3,260.00 mg/l and the majority of the samples have either tolerable or unacceptable level of hardness. The highest values are observed in samples collected from wells completed in areas where the silts and clays of glaciomarine or marine origins outcrop at the surface.

10.2.7 Total Dissolved Solids

The concentrations of total dissolved solids range from 72.00 to 7,800.00 mg/l. All the samples collected from wells completed in areas where the Wentworth Till and Quaternary Unit 21 (undifferentiated silty clay to silt till) outcrop at the surface have concentrations of total dissolved solids below the PDWO.

Samples collected from wells completed in areas where other overburden deposits outcrop at the surface show various degrees of exceedance. The degree of exceedance in terms of total dissolved solids ranges from 15% for wells completed in areas where the Port Stanley Till outcrops at the surface to 80% for wells completed in areas where sands and gravel of glaciomarine and marine origins outcrop at the surface.

10.2.8 Overburden Ground water Types

In order to determine the ground water types in wells completed in the overburden, Durov Analysis was performed on 466 samples. Approximately, 64% of the water samples are of calcium-bicarbonate type, 11.4% are of bicarbonate type, 6.2% are of sodium-potassium-bicarbonate type, 6.2% are of calcium-sulphate-nitrate type, 4.1% are of calcium type, 3.2% are of sodium-potassium-chloride type and the remaining 4.9% are mainly of magnesium-bicarbonate type or show no dominant type.

10.3 GENERAL CHARACTERISTICS OF NATURAL GROUND WATER QUALITY ENCOUNTERED IN BEDROCK AND OVERBURDEN WELLS

Six parametrs were used to assess the general characteristics of natural ground water quality encountered in bedrock and overburden wells in southern Ontario. These parametrs are: sodium, iron, chloride, sulphate, hardness, and total dissolved solids. The nitrate parameter was not considered in this assessment because the nitrate levels in natural ground waters are usually within the PDWO and high levels of nitrate nitrogen (> 10.00 mg/l) are indicative of water contamination.

A semi-quantitative scale that is based on the percent of samples exceeding the PDWOs for sodium, iron, chloride, sulphates or total dissolved solids was adopted to characterize the general ground water quality in the sampled wells. The scale is as follows:

Percent PDWO exceedance	General Water Quality
0 - 10	Excellent
10 - 20	Very Good
20 - 30	Good
30 - 40	Medium
40 - 50	Low
>50	Poor

Since the PDWO for water hardness is an operational guideline that was established to ensure the efficient treatment of water, the scale used to describe the parameter hardness in this assessment is the same scale that was used to describe the hardness variations that were obtained in various chemical analyses.

The description "excellent" indicates that at least 90% of the sampled wells meet the PDWO in terms of a given parameter. The description "poor", on the other hand, indicates that less than 50% of the sampled wells have water that meets the PDWO for a given parameter.

If one is to believe that the water quality of the sampled wells are represetative of the general ground water quality, then the above scale may be extended to describe the ground water quality in various bedrock hydrogeologic units and in areas where various overburden deposits outcrop at the surface.

Table 10 gives the results of the assessment. The table indicates that ground water quality in both the bedrock and the overburden is often good, very good or excellent in terms sodium, chloride, sulphate or total dissolved solids. This confirms the information contained in the WWIS database regarding the kind of water encountered in various wells. The WWIS database indicates that approximately 98.8% of all overburden and 93.9% of bedrock wells yield fresh water. In terms of hardness, the ground water quality in both the bedrock and the overburden often fails to meet the PDWO.

11. CONCLUSIONS

This report represents an attempt to describe on a regional scale the hydrogeology of southern Ontario. It also illustrates the wealth of information contained in the MOEE WWIS database and how this information can be effectively used in conjunction with RAISON GIS system.

Since the inception of the WWIS database, no hydrogeologic investigation has been conducted in Ontario without strong reliance on it. In the past, however, the analysis and interpretation of the information obtained from the WWIS database for a given area was done manually. Therefore, only a limited number of well records could be considered. In comparison, over 215,000 well records were examined in this report. Of these, over 173,000 records that have the highest degree of accuracy in terms of well location and elevation were selected for further analysis. Given that each well record contains up to 212 parameter, the database that was considered is extremely large.

Recent advances the area of GIS systems made it feasible to consider large databases, to present the data on thematic maps, and to conduct numerous analyses and interpretations within a relatively short time frame. RAISON is such a GIS system, and is suitable for use with WWIS database.

Numerous hydrogeologic techniques were developed by MOEE staff to enhance the RAISON capabilities. These techniques were used to generate for the first time several unique maps of southern Ontario and to conduct numerous hydrogeologic analyses.

The bedrock and overburden well location maps of southern Ontario (Figures 6 and 17) show not only the areal distribution of the wells but also the areas where data are scarce or missing. These two maps can be used to identify areas where additional well information is required and to design effective data collection and monitoring programs.

The bedrock topography map of southern Ontario (Figure 7) shows the topography of the area during preglacial times and how similar it is to present-day topography. It also reveals the location and extent of major topographic features of significant hydrogeologic importance such as the Dundalk Dome, the Laurentian Channel, and the Dundas Valley.

The overburden thickness map of southern Ontario (Figure 18) shows the areal distribution of the overburden and the variations of its thickness. The map explains why the overburden wells are clustered in areas where the overburden deposits are thick and why the bedrock wells are clustered in areas where the overburden is thin or missing.

The significance of topography on the ground water flow regimes is illustrated in the bedrock and overburden ground water level maps (Figures 20 and 21). The maps reveal that ground water regional divides coincide closely with major basin topographic divides. It also highlights the topographic control exerted by the Laurentian Highlands physiographic region and the Dundalk Dome on the ground water flow regimes.

The enhanced RAISON statistical techniques made it feasible to select large data sets for wells completed in various bedrock units and in areas where different overburden deposits outcrop at the surface. These techniques were used to determine the specific capacity and transmissivity distributions for the selected data sets, and to identify the water-yielding capabilities of 18 bedrock hydrogeologic units (Figure 15).

In terms of water-yielding capability, the Bois Blanc, Detroit River Group, Salina, Bass Island, Dundee, and Amable-Lockport-Guelph hydrogeologic units have been identified as the best hydrogeologic units within the bedrock

in southern Ontario. Areas where sands and gravels of glacial, glaciolacustrine and marine origins outcrop at the surface have been identified as the areas where wells have the highest water-yielding capabilities.

The Streamflow Separation Program was used to determine the monthly and annual ground water recharge for 33 gauging stations located in small watersheds in southern Ontario. Care was taken to ensure that the size of the watersheds is less than 200 km^2, that streamflows at all the stations are natural flows, and that the period of record at each station is long enough to allow for the estimation of the long-term means of ground water discharge and recharge.

The long-term means of annual ground water discharge, calculated for the 33 stations, range from 83.34 to 284.88 mm. Given that the records at the selected stations is long enough for the change in soil moisture storage to approaches zero, it is possible to assume that the long-term means of monthly and annual ground water discharge, calculated for the 33 gauging stations, are equal to their long-term means of monthly and annual ground water recharge.

An evaluation of natural ground water quality in southern Ontario revealed that it is often good within both the bedrock and the overburden in terms of sodium, chloride, sulphate and total dissolved solids. This confirms the information contained in the WWIS database regarding the kind of water encountered in various bedrock and overburden wells. The WWIS database indicates that approximately 93.9% of the bedrock overburden wells and 98.8% of the overburden wells yield fresh water. In terms of iron and hardness, however, the ground water quality in both the bedrock and the overburden fails at times to meet the PDWOs.

The DUROV Water Quality Analyzer computer program was used to determine the various types of ground water encountered in bedrock and overburden wells. Most samples indicate that ground water in both the bedrock and the overburden is of bicarbonate or calcium-bicarbonate type.

Given the complexity of the hydrogeology of southern Ontario, future researchers will no doubt make many new findings and, in doing so, improve our understanding of the ground water regimes in this part of the province.

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TABLES

Table 1. Kind of water encountered in bedrock wells by county.

County	Fresh	Salty	Sulphurous	Mineral	Gas	Unknown	Total
BRANT	593	0	90	11	0	10	704
BRUCE	5592	35	133	43	1	185	5989
DUFFERIN	1441	10	1	18	0	21	1491
DUNDAS	1614	9	54	1	0	12	1690
DURHAM	748	20	36	4	4	44	856
ELGIN	74	1	45	5	2	4	131
ESSEX	1174	13	539	5	2	17	1750
FRONTENAC	5849	114	185	8	5	1083	7244
GLENGARRY	1498	4	59	0	0	12	1573
GRENVILLE	3167	7	32	4	0	19	3229
GREY	6421	47	74	76	3	79	6701
HALDIMAND	788	5	169	29	0	19	1010
HALIBURTON	1140	2	0	3	0	44	1189
HALTON	3171	62	15	19	0	39	3306
HASTINGS	5486	44	305	33	0	80	5948
HURON	2759	3	45	1	0	30	2838
KENT	2067	68	48	13	63	55	2314
LAMBTON	2238	40	313	21	38	29	2679
LANARK	5281	11	29	3	0	71	5395
LEEDS	5490	3	5	0	0	174	5672
LENNOX & ADDINGTON	3184	70	252	34	0	74	3614
LINCOLN (NIAGARA)	1492	52	97	40	0	20	1701
MIDDLESEX	1324	15	373	17	5	52	1786
MUSKOKA	1748	11	0	11	0	29	1799
NORFOLK	392	3	231	23	1	12	662
NORTHUMBERLAND	1588	20	93	17	0	24	1742
OTTAWA-CARLETON	13462	129	589	22	0	156	14358
OXFORD	2601	7	188	47	0	51	2894
PEEL	1563	96	4	35	0	38	1736
PERTH	2252	2	24	2	0	27	2308
PETERBOROUGH	4995	52	141	11	0	325	5524
PRESCOTT	1107	41	31	5	0	11	1195
PRINCE EDWARD	2409	56	100	13	0	20	2598
RENFREW	4936	17	22	7	0	211	5193
RUSSELL	1254	56	70	5	0	21	1406
SIMCOE	2865	49	172	34	1	164	3285
STORMONT	1240	3	69	2	0	7	1321
VICTORIA	3775	51	342	11	1	278	4458
WATERLOO	1267	1	44	36	0	49	1397
WELLAND (NIAGARA)	1153	3	313	15	0	11	1495
WELLINGTON	4644	3	35	4	0	108	4794
WENTWORTH	4800	13	427	6	0	28	5274
YORK	1211	41	32	9	0	67	1360
Total	121853	1289	5826	703	126	3812	133609

Table 2. Water-yielding capabilities of various bedrock hydrogeologic units in southern Ontario.

Hydrogeologic unit	Geographic location	Total number of wells	Number of wells in samples	Transmissivity m²/day			Water-yielding capability of unit
				10 Percentile	Geometric mean	90 Percentile	
Precamberian	East-central Ontario	12381	7875	0.40	4.20	42.50	Poor
Nepean-March -Oxford	Eastern Ontario	17642	7418	0.45	20.04	120.51	Good
Rockcliffe	Eastern Ontario	2117	1771	2.13	15.52	103.90	Good
Ottawa Group	Eastern Ontario	10357	7251	1.27	11.70	70.94	Good
Simcoe Group	Central Ontario	28172	6414	0.71	5.70	63.84	Fair
Billings-Carlsbad-Queenston	Eastern Ontario	1106	969	0.98	5.79	52.17	Fair
Blue Mountain-Georgian Bay	Central Ontario	2130	1293	0.49	2.93	36.52	Poor
Queenston	Central Ontario	3580	2505	0.47	2.66	27.95	Poor
Amabel-Lockport-Guelph	Southwestern Ontario						
-Amabel		7549	6516	1.54	15.46	134.80	Good
-Lockport		1951	1662	1.69	20.60	141.00	Good
Guelph		14059	6072	1.37	12.05	104.90	Good
Salina	Southwestern Ontario	3756	2994	3.16	28.18	189.00	Very Good
Bass Island	Southwestern Ontario	807	739	5.44	30.92	179.00	Very Good
Bois Blank	Southwestern Ontario	1261	1069	6.28	40.45	274.50	Excellent
Detriot River Group	Southwestern Ontario	7818	6762	3.98	30.92	214.00	Very Good
Dundee	Southwestern Ontario	5030	4199	3.09	27.08	169.10	Very Good
Hamilton Group	Southwestern Ontario	2208	1044	0.55	5.33	63.45	Fair
Kettle point	Southwestern Ontario	6145	3096	0.90	8.57	82.85	Fair

Table 3. Kind of water encountered in overburden wells by county.

County	Fresh	Salty	Sulphurous	Mineral	Gas	Unknown	Total
BRANT	1642	1	7	1	0	28	1679
BRUCE	531	0	11	4	0	110	656
DUFFERIN	405	0	1	14	0	72	492
DUNDAS	131	0	1	0	0	0	132
DURHAM	7650	10	15	6	1	355	8037
ELGIN	3333	7	41	5	3	26	3415
ESSEX	592	2	82	4	0	8	688
FRONTENAC	81	1	1	0	0	24	107
GLENGARRY	402	0	8	1	0	5	416
GRENVILLE	68	0	2	0	0	0	70
GREY	1244	3	6	4	1	32	1290
HALDIMAND	186	0	9	0	0	2	197
HALIBURTON	164	0	0	1	0	10	175
HALTON	1175	8	1	2	0	5	1191
HASTINGS	806	4	3	0	0	3	816
HURON	505	3	0	0	0	7	515
KENT	1694	24	11	0	17	20	1766
LAMBTON	1161	12	36	1	9	9	1228
LANARK	61	0	0	0	0	2	63
LEEDS	80	0	0	0	0	8	88
LENNOX & ADDINGTON	111	0	1	0	0	1	113
LINCOLN (NIAGARA)	301	4	14	3	0	2	324
MIDDLESEX	7386	4	52	1	1	127	7571
MUSKOKA	332	2	0	0	0	4	338
NORFOLK	3136	2	20	8	1	101	3268
NORTHUMBERLAND	2648	8	7	15	1	64	2743
OTTAWA-CARLETON	1152	24	35	6	0	12	1229
OXFORD	2843	5	19	9	0	56	2932
PEEL	2132	8	1	6	0	432	2579
PERTH	465	1	0	1	0	4	471
PETERBOROUGH	3154	3	5	3	0	137	3302
PRESCOTT	307	28	6	2	0	3	346
PRINCE EDWARD	60	0	0	1	0	0	61
RENFREW	511	4	0	0	0	53	568
RUSSELL	251	32	16	5	0	0	304
SIMCOE	11663	20	43	29	0	1555	13311
STORMONT	180	0	5	1	0	5	191
VICTORIA	2586	2	6	6	0	176	2776
WATERLOO	2631	3	9	12	0	58	2713
WELLAND (NIAGARA)	335	2	19	3	0	12	371
WELLINGTON	1109	0	2	5	0	27	1143
WENTWORTH	1213	2	18	0	0	15	1248
YORK	10317	11	19	14	0	948	11309
Total	76734	240	532	173	34	4519	82232

Table 4. Summary of Quaternary sand and gravel deposits.

Age	Stratigraphic Unit or Event	Origin of Deposits
Holocene	Lake Nipissing	Shore bluffs, bog and swamp deposits, and alluvial deposits
Late Wisconsinan		
- Greatlakean Stade	Champlain Sea	Glaciofluvial and glaciomoraine
- Two Creeks Interstade	Lakes Iroquois Early, Main and Lake Alqonquin Lakes	Glaciofluvial and glaciolacustrine
- Port Huron Stade	Wentworth Drift	Glaciofluvial
	Lakes Whittlesey, Warren, Lundy, Peel and Scomberg	Glaciolacustrine, and shore bluffs
- Mackinaw Interstade	Oak Ridges moraine	Glaciofluvial
- Port Bruce Stade	Port Stanley Drift	Glaciofluvial
	Maumee Lakes I,II, III and IV	Glaciolacustrine
- Erie Interstadial	Malihide Formation	Glaciolacustrine
	Wildwood Silts	Glaciolacustrine
Middle Wisconsinan	Thorncliffe Formation	Glaciofluvial and glaciolacustrine
Early Wisconsinan	Scarborough Formation	Glaciofluvial
	Pottery Road Formation	Alluvial
Sangamonian	Don Formation	Glaciofluvial

Table 5. **Selected gauging stations in Southern Ontario used to calculate long-term means of annual ground water discharge/recharge.**

STATION NUMBER	STATION NAME	PERIOD OF RECORD	AREA (Km²)
02EC009	HOLLAND RIVER AT BALDWIN near	1965-1993	181
02EC010	SCHOMBERG RIVER NEAR SCHOMBERG	1966-1993	42.9
02ED007	COLDWATER RIVER AT COLDWATER	1965-1993	177
02ED009	WILLOW CREEK ABOVE LITTLE LAKE	1973-1993	94.8
02ED010	WILLOW CREEK AT MIDHURST	1973-1993	127
02ED014	PINE RIVER NEAR EVERETT	1967-1993	195
02FC011	CARRICK CREEK NEAR CARLSRUHE Bruce	1953-1993	163
02FC017	BEATTY SAUGEEN RIVER NEAR HOLSTEIN	1985-1993	50.1
02FD001	PINE RIVER AT LURGAN	1974-1993	154
02FD002	LUCKNOW RIVER AT LUCKNOW Huron	1979-1993	54.9
02FE011	MIDDLE RIVER NEAR HARRISTON Georgian Bay	1981-1993	112
02FE014	BLYTH BROOK BELOW BLYTH	1984-1993	77.7
02FF009	AUSABLE RIVER NEAR EXETER	1984-1993	113
02GC029	KETTLE CREEK ABOVE ST. THOMAS	1985-1993	135
02GC031	DODD CREEK BELOW PAYNES MILLS Elgin	1987-1993	95.4
02GD010	FISH CREEK NEAR PROSPECT HILL	1945-1993	150
02GD020	WAUBUNO CREEK NEAR DORCHESTER	1965-1993	108
02GE005	DINGMAN CREEK BELOWLAMBETH	1965-1993	146
02GH002	RUSCOM RIVER NEAR RUSCOM STATION	1971-1993	125
02GH003	CANARD RIVER NEAR LUKERVILLE	1967-1993	159
02HD006	BOWMANVILLE CREEK AT BOWMANVILLE	1959-1993	82.9
02HD009	WILMOT CREEK NEAR NEWCASTLE	1965-1990	82.6
02HD013	HARMONY CREEK AT OSHAWA	1980-1993	41.6
02HG001	MARIPOSA BROOK NEAR LITTLE BRITAIN	1982-1993	189
02HJ001	JACKSON CREEK AT PETERBOROUGH	1962-1993	110
02HK007	COLD CREEK AT ORLAND Northumberland	1981-1993	159
02HK008	RAWDON CREEK NEAR WEST HUNTINGDON	1982-1993	86.7
02HM004	WILTON CREEK NEAR NAPANEE	1965-1993	112
02HM005	COLLINS CREEK NEAR KINGSTON	1969-1995	155
02LB020	SOUTH CASTOR RIVER AT KENMORE	1978-1993	189
02LB022	PAYNE RIVER NEAR BERWICK	1976-1993	152
02MC026	RIVERE BEAUDETTE NEAR NEVIS	1983-1993	124
02MC028	RIVERE DELISLE NEAR ALEXANDARIA	1985-1993	85.4

Table 6. **Long-term means of monthly and annual ground water discharge/recharge at selected gauging stations in southern Ontario.**

Station Number	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual (mm)
02EC009	9.03	11.19	21.5	19.56	10.87	6.99	6.55	6.35	6.35	7.37	9.42	9.74	124.92
02EC010	7.04	9.7	24.55	20.42	7.25	3.75	2.93	2.57	2.84	4.16	5.74	7.4	98.35
02ED007	20.63	20.25	32.98	34.41	21.4	17.17	16.03	15.39	16.95	19.46	21.98	23.22	259.87
02ED009	9.09	9.77	34.02	30.89	8.99	4.53	2.95	1.87	4.68	5.87	11.43	12	136.09
02ED010	6.76	6.4	21.73	25.3	8.3	3.63	2.78	2.23	4.1	6.37	8.08	9.16	104.84
02ED014	15.41	15.46	25.14	28.15	18.73	13.39	12.99	11.71	11.15	12.17	14.43	16.81	195.54
02FC011	17.48	19.35	36.16	33.03	14.42	8.38	5.21	5.39	6.44	9.44	13.47	18.66	187.43
02FC017	17.46	11.07	30.97	24.48	10.64	7.65	5.42	4.34	7.24	10.91	15.15	12.52	157.85
02FD001	6.74	4.68	13.84	15.56	7.13	5.36	3.76	3.54	3.96	4.95	7.96	5.86	83.34
02FD002	29.32	28.45	52.18	34.67	15.5	11.22	5.35	4.85	11.14	13.56	22.38	28.24	256.86
02FE011	20.64	26.42	57.27	27.76	9.39	4.33	1.14	1.88	7.47	9.88	19.79	23.58	209.55
02FE014	26.64	18.63	53.37	33.53	11.21	7.23	3.67	4.2	10.69	16.1	28.21	25.55	239.03
02FF009	21.2	23.96	48.72	36	12.98	6.21	3.3	3.46	6.79	11.4	19.34	24.38	217.74
02GC029	20.28	16.2	30.15	20.96	6.19	3.65	2.53	3.14	5.36	9.06	19.19	20.02	156.73
02GC031	19.05	19.55	49.03	35.19	12.55	8.03	3.87	3.78	8.63	10.55	22.59	21.82	214.64
02GD010	18.96	20.96	43.25	32.36	13.18	6.25	3.62	3.15	4.9	9.3	15.18	22.14	193.25
02GD020	16.29	19.09	36.45	23.47	9.88	5.11	3.6	2.89	4.49	7.19	13	19.2	160.66
02GE005	20.28	16.2	30.15	20.96	6.19	3.65	2.53	3.14	5.36	9.06	19.19	20.02	156.73
02GH002	21.88	18.57	26.18	20.87	6.66	3.59	2.39	3.28	9.26	8.05	21.69	16.03	158.45
02GH003	21.56	13.16	31.63	19.89	4.58	1.44	2.78	4.39	6.82	6.84	21.73	28.41	163.23
02HD006	24.32	27.11	43.65	37.23	23.87	17.36	16.52	16.37	16.26	17.85	21.16	23.18	284.88
02HD009	18.83	22.1	33.63	28.56	19.54	15.31	13.16	12.43	12.99	14.62	16.91	18.81	226.89
02HD013	14.37	17.57	30.74	22.49	9.77	6.16	4.28	3.63	4.97	6.94	13.88	16.37	151.17
02HG001	12.22	15.3	28.84	18.24	8.22	6.51	3.75	1.9	5.36	5.98	10.05	15.84	132.21
02HJ001	11.32	15.04	28.44	19.95	7.33	8	7.36	2.14	9.97	7.05	11.5	15.72	143.82
02HK007	24.32	27.11	43.65	37.23	23.87	17.36	16.52	16.37	16.26	17.85	21.16	23.18	284.88
02HK008	18.83	22.1	33.6	28.56	19.54	15.31	13.16	12.43	12.99	14.62	16.91	18.81	226.86
02HM004	16.15	16.73	40.13	31.55	11.85	5.6	2.29	1.75	4.24	5.55	14.38	19.05	169.27
02HM005	19.8	19.45	47.2	41.58	15.2	6.56	2.66	1.83	5.07	7.74	16.93	24.69	208.71
02LB020	8.73	10.11	34.38	42.59	13.04	5.6	3.66	3.11	4.86	6.98	10.07	13.7	156.83
02LB022	9.39	11.11	35.63	44.74	12.92	4.91	2.85	1.82	3.41	7.4	12.34	14.46	160.98
02MC026	11.75	11.26	34.08	44.55	11.39	5.02	2.81	2.33	2.7	5.56	12.68	15.21	159.34
02MC028	10.77	9.02	29.08	44.38	12.55	6.64	4.04	1.89	1.91	5.96	12.1	13.06	151.4

Table 7. Ground water quality in various bedrock hydrogeologic units, (all values in mg/l).

Hydrogeologic Unit		Sodium (Na)	Sulphate (SO_4)	Chloride (Cl)	Nitrate (NO_3 as N)	Total Iron (Fe)	Total Dissolved Solids	Total Hardness (as $CaCO_3$)
Precambrian	Number Of Samples	6	4	8	7	8	3	8
	Mean	40.50	189.11	53.81	0.98	7.28	412.33	250.00
	Minimum	16.00	9.75	5.80	0.02	0.05	261.00	112.00
	Maximum	123.00	635.00	149.00	3.60	57.00	514.00	550.00
	% exceeding the PDWO objective	0	25	0	0	43	0	-
Nepean-March-Oxford	Number Of Samples	32	28	33	33	33	25	33
	Mean	21.91	55.71	41.00	4.40	1.32	468.28	320.79
	Minimum	1.00	15.00	3.00	0.02	0.05	268.00	92.00
	Maximum	138.00	180.00	272.00	40.00	15.00	1380.00	870.00
	% exceeding the PDWO objective	0	0	3	9	27	28	-
Rockcliffe	Number Of Samples	1	1	1	1	1	1	1
	Value	21.00	34.00	63.00	0.20	0.05	304.00	220.00
Ottawa Group	Number Of Samples	39	37	39	39	38	29	39
	Mean	166.52	57.03	173.47	1.05	0.59	732.90	277.92
	Minimum	3.60	3.00	4.00	0.02	0.05	276.00	30.00
	Maximum	1310.00	435.00	1850.00	8.00	7.50	2874.00	530.00
	% exceeding the PDWO objective	21	3	10	0	45	62	-
Simcoe Group	Number Of Samples	34	35	38	36	38	33	38
	Mean	106.25	137.10	107.92	0.45	1.36	647.33	285.89
	Minimum	4.00	1.00	0.50	0.03	0.01	189.00	31.00
	Maximum	1090.00	1950.00	847.00	4.00	26.00	4530.00	1040.00
	% exceeding the PDWO objective	15	11	11	0	37	42	-

Table 7. (cont'd)

Hydrogeologic Unit		Sodium (Na)	Sulphate (SO4)	Chloride (Cl)	Nitrate (NO3 as N)	Total Iron (Fe)	Total Dissolved Solids	Total Hardness (as CaCO3)
Billings-Carlsbad-Queenston (eastern Ontario)	Number Of Samples	10	10	10	10	9	10	10
	Mean	300.30	25.60	304.30	0.10	2.43	947.10	202.30
	Minimum	1.00	3.00	5.00	0.10	0.10	234.00	10.00
	Maximum	1090.00	70.00	1142.00	0.10	19.00	2874.00	575.00
	% exceeding the PDWO objective	50	0	30	0	33	70	-
Blue Mountain-Georgian Bay	Number Of Samples	12	12	13	13	13	7	13
	Mean	109.04	31.50	137.31	1.73	0.41	686.00	262.69
	Minimum	9.00	2.00	2.00	0.10	0.01	360.00	88.00
	Maximum	285.00	130.00	441.00	9.40	1.60	950.00	756.00
	% exceeding the PDWO objective	25	0	15	0	31	71	-
Queenston (central Ontario)	Number Of Samples	12	12	12	12	5	8	12
	Mean	88.58	250.58	123.44	0.98	0.20	953.25	472.08
	Minimum	1.60	18.40	3.00	0.01	0.05	251.00	109.00
	Maximum	270.00	1220.00	445.00	6.20	0.55	2580.00	1460.00
	% exceeding the PDWO objective	8	33	17	0	20	62	-
Clinton-Cataract Groups	Number Of Samples	3	3	3	3	3	-	3
	Mean	12.33	43.67	37.67	0.97	2.07	-	293.67
	Minimum	4.00	26.00	2.00	0.10	0.15	-	217.00
	Maximum	17.00	65.00	69.00	2.40	5.70	-	360.00
	% exceeding the PDWO objective	0	0	0	0	67	-	-
Amabel	Number Of Samples	96	96	96	95	19	56	96
	Mean	15.76	90.23	27.61	1.47	0.49	479.13	348.92
	Minimum	2.00	1.00	0.10	0.02	0.01	211.00	183.00
	Maximum	92.30	1300.00	182.00	13.00	3.00	2270.00	1515.00
	% exceeding the PDWO objective	0	6	0	1	37	21	-

Table 7. (cont'd)

Hydrogeologic Unit		Sodium (Na)	Sulphate (SO4)	Chloride (Cl)	Nitrate (NO3 as N)	Total Iron (Fe)	Total Dissolved Solids	Total Hardness (as CaCO3)
Guelph	Number Of Samples	46	47	48	46	47	43	48
	Mean	36.48	243.02	53.54	2.00	1.23	733.26	469.44
	Minimum	2.00	2.00	0.20	0.01	0.01	215.00	73.00
	Maximum	295.00	1600.00	770.00	17.00	33.00	3405.00	1960.00
	% exceeding the PDWO objective	2	23	4	7	60	35	-
Salina	Number Of Samples	62	63	63	55	63	62	63
	Mean	68.62	975.22	38.16	2.08	1.77	1735.58	1110.53
	Minimum	2.50	4.00	0.20	0.01	0.03	235.00	168.00
	Maximum	391.00	2570.00	590.00	37.00	7.00	4190.00	2860.00
	% exceeding the PDWO objective	11	65	5	5	68	69	-
Bass Island	Number Of Samples	15	17	19	14	19	15	19
	Mean	32.33	503.53	14.38	2.39	1.50	1220.00	788.26
	Minimum	3.00	5.00	0.20	0.01	0.05	235.00	93.90
	Maximum	124.00	2197.00	66.00	21.00	13.00	3840.00	2520.00
	% exceeding the PDWO objective	0	35	0	7	47	47	-
Bois Blanc	Number Of Samples	21	22	23	21	23	21	23
	Mean	31.50	323.27	14.62	1.21	1.14	858.38	599.93
	Minimum	5.00	4.00	0.20	0.01	0.05	225.00	162.00
	Maximum	174.00	1875.00	53.00	13.00	5.30	3040.00	1740.00
	% exceeding the PDWO objective	0	32	0	5	65	48	-
Detroit River Group	Number Of Samples	57	77	77	42	76	54	76
	Mean	73.01	282.08	112.16	1.25	2.15	1185.63	578.45
	Minimum	1.00	0.40	0.20	0.01	<0.01	166.00	54.00
	Maximum	2125.00	3100.00	6820.00	11.00	70.00	13400.00	4600.00
	% exceeding the PDWO objective	5	22	1	2	64	50	-

Table 7. (cont'd)

Hydrogeologic Unit		Sodium (Na)	Sulphate (SO4)	Chloride (Cl)	Nitrate (NO3 as N)	Total Iron (Fe)	Total Dissolved Solids	Total Hardness (as CaCO3)
Dundee	Number Of Samples	48	75	76	29	78	44	78
	Mean	123.82	142.07	174.91	1.00	2.25	925.82	378.22
	Minimum	8.00	1.00	1.00	0.01	0.01	160.00	37.00
	Maximum	1538.00	1430.00	2660.00	8.00	79.00	5800.00	2230.00
	% exceeding the PDWO objective	10	13	14	0	59	45	-
Hamilton Group	Number Of Samples	4	10	11	3	11	4	11
	Mean	161.25	31.00	350.40	1.44	1.65	681.50	197.80
	Minimum	8.00	1.00	11.00	0.01	0.05	396.00	73.00
	Maximum	241.00	85.00	967.00	3.10	3.40	1000.00	336.00
	% exceeding the PDWO objective	50	10	45	0	64	75	-
Kettle Point	Number Of Samples	6	14	22	-	21	5	21
	Mean	478.67	11.43	261.82	-	0.82	1506.00	99.00
	Minimum	28.00	1.00	26.00	-	0.20	400.00	31.00
	Maximum	2115.00	82.00	3168.00	-	3.50	5530.00	312.00
	% exceeding the PDWO objective	50	10	45	0	64	75	-

Table 8. Ground water quality for wells completed in areas where various overburden deposits outcrop at surface, (all values in mg/l).

Deposit		SODIUM (Na)	SULPHATE (SO4)	CHLORIDE (Cl)	NITRATE (NO3 as N)	TOTAL IRON (Fe)	TOTAL DISSOLVED SOLIDS	TOTAL HARDNESS (AS CaCO3)
Catfish Creek Till	Number Of Samples	0	4	4	0	4	0	4
	Mean	-	30.00	48.50	-	0.85	-	276.50
	Minimum	-	13.00	5.00	-	0.05	-	158.00
	Maximum	-	48.00	162.00	-	1.70	-	464.00
	% exceeding the PDWO objective	-	0	0	-	75	-	-
Port Stanley Till	Number Of Samples	60	76	77	60	73	52	80
	Mean	40.23	35.04	60.13	1.59	2.49	366.15	213.89
	Minimum	2.00	<0.01	0.10	<0.01	0.05	130.00	40.00
	Maximum	231.00	182.00	2424.00	36.00	94.00	1000.00	820.00
	% exceeding the PDWO objective	3	0	4	7	67	15	-
Tavistock Till	Number Of Samples	15	31	32	7	32	15	32
	Mean	248.80	33.85	304.63	3.71	1.38	961.93	233.47
	Minimum	8.00	<0.01	1.00	0.10	<0.01	255.00	50.00
	Maximum	1430.00	400.00	2328.00	21.00	9.50	4300.00	470.00
	% exceeding the PDWO objective	33	3	25	14	66	60	-
Mornington Till	Number Of Samples	5	5	5	5	5	5	5
	Mean	21.80	357.40	9.80	8.26	2.62	898.00	610.60
	Minimum	17.00	2.00	1.00	0.10	0.10	285.00	172.00
	Maximum	27.00	1400.00	22.00	22.00	7.60	2320.00	1570.00
	% exceeding the PDWO objective	0	20	0	40	60	80	-

Tabel 8. (cont'd)

Deposit		SODIUM (Na)	SULPHATE (SO4)	CHLORIDE (Cl)	NITRATE (NO3 as N)	TOTAL IRON (Fe)	TOTAL DISSOLVED SOLIDS	TOTAL HARDNESS (AS CaCO3)
Elma Till	Number Of Samples	7	8	8	7	8	7	8
	Mean	14.8	31.4	23.4	2.2	1.2	440.3	301.0
	Minimum	3.0	9.0	2.0	0.1	<0.01	285.0	124.0
	Maximum	33.0	82.0	138.0	6.8	6.8	800.0	518.0
	% exceeding the PDWO objective	0	0	0	0	63	29	-
Rannoch Till	Number Of Samples	4	12	11	7	12	4	12
	Mean	23.25	35.75	14.82	3.99	0.10	443.75	251.42
	Minimum	5.00	3.00	1.00	0.10	0.01	350.00	42.00
	Maximum	45.00	125.00	54.00	7.90	0.45	524.00	391.00
	% exceeding the PDWO objective	0	0	0	0	8	25	-
Newmarket Till	Number Of Samples	22	22	23	22	22	22	23
	Mean	21.50	30.13	22.60	3.62	0.51	397.70	269.10
	Minimum	2.00	1.00	1.00	0.02	0.10	254.00	142.00
	Maximum	148.00	95.00	226.00	37.00	1.60	735.00	434.00
	% exceeding the PDWO objective	0	0	0	5	45	23	-
Wentworth Till	Number Of Samples	10	10	10	7	8	6	10
	Mean	8.29	64.73	7.39	1.40	2.06	305.67	279.80
	Minimum	2.80	9.00	2.00	<0.01	<0.01	271.00	142.00
	Maximum	16.00	195.00	18.00	6.50	5.80	347.00	408.00
	% exceeding the PDWO objective	0	0	0	0	75	0	-
Halton Till	Number Of Samples	72	73	73	73	43	51	73
	Mean	25.95	48.10	52.86	2.68	0.78	466.54	335.11
	Maximum	360.00	680.00	677.00	33.00	8.10	2590.00	1100.00
	% exceeding the PDWO objective	1	1	5	8	47	31	-

Tabel 8. (cont'd)

Deposit		SODIUM (Na)	SULPHATE (SO4)	CHLORIDE (Cl)	NITRATE (NO3 as N)	TOTAL IRON (Fe)	TOTAL DISSOLVED SOLIDS	TOTAL HARDNESS (AS CaCO3)
Kettleby Till	Number Of Samples	7	6	7	6	7	6	7
	Mean	19.29	62.33	36.71	11.37	0.26	532.17	391.29
	Minimum	5.00	29.00	9.00	0.10	0.10	318.00	249.00
	Maximum	32 00	93.00	69.00	29.00	0.95	672.00	478.00
	% exceeding the PDWO objective	0	0	0	33	14	50	-
St. Joseph Till	Number Of Samples	7	7	7	7	7	7	7
	Mean	37.63	47.00	4.57	0.19	0.40	303.29	155.57
	Minimum	5.00	8.00	0.20	0.04	0.17	183.00	85.00
	Maximum	63.00	150.00	12.80	0.52	0.70	528.00	316.00
	% exceeding the PDWO objective	0	0	0	0	57	14	-
Unit 19 (Undifferentiated sandy-silt to silt till)	Number Of Samples	19	20	20	20	19	18	20
	Mean	26.89	39.74	52.32	4.79	0.75	516.00	333.84
	Minimum	2.00	4.00	1.00	0.10	0.02	192.00	160 00
	Maximum	135.00	112.00	420.00	30.00	11.00	1540.00	740.00
	% exceeding the PDWO objective	0	0	5	10	16	33	-
Unit 21 (Undifferentiated silty-clay to silt till)	Number Of Samples	3	3	3	3	3	3	3
	Mean	18.00	8.00	2.33	0.10	0.82	191.00	131.00
	Minimum	4.00	2.00	1.00	0.10	0.40	146.00	44.00
	Maximum	39.00	15.00	3.00	0.10	1.40	235.00	201.00
	% exceeding the PDWO objective	0	0	0	0	100	0	-
Ice-contact deposits	Number Of Samples	55	58	58	55	41	48	57
	Mean	25.42	56.94	28.06	2.28	0.75	411.68	314.93
	Minimum	1.60	0.10	0.10	0.01	0.01	66.08	99.00
	Maximum	485.00	600.00	228.00	19.00	5.20	1200.00	880.00
	% exceeding the PDWO objective	4	5	0	7	44	23	-

Tabel 8. (cont'd)

Deposit		SODIUM (Na)	SULPHATE (SO4)	CHLORIDE (Cl)	NITRATE (NO3 as N)	TOTAL IRON (Fe)	TOTAL DISSOLVED SOLIDS	TOTAL HARDNESS (AS CaCO3)
Outwash deposits	Number Of Samples	62	76	74	61	42	42	74
	Mean	23.04	105.14	29.14	2.41	0.82	539.10	321.36
	Minimum	2.00	2.00	1.20	<0.01	0.05	210.00	59.00
	Maximum	416.00	1300.00	284.00	29.00	9.10	2200.00	1490.00
	% exceeding the PDWO objective	2	7	1	5	33	21	-
Glaciolacustrine sand and gravel deposits	Number Of Samples	170	184	191	170	171	123	191
	Mean	25.92	97.01	37.44	3.47	0.92	506.13	302.80
	Minimum	<0.01	<0.01	1.00	<0.01	<0.01	160.00	29.00
	Maximum	403.00	2100.00	549.00	66.00	11.00	3890.00	1940.00
	% exceeding the PDWO objective	2	5	4	8	44	27	-
Glaciomarine and marine sand and gravel deposits	Number Of Samples	5	5	5	5	5	5	5
	Mean	72.80	63.20	75.20	6.86	0.54	680.20	410.00
	Minimum	16.00	5.00	24.00	0.10	0.05	277.00	148.00
	Maximum	230.00	120.00	112.00	11.00	1.30	908.00	652.00
	% exceeding the PDWO objective	20	0	0	40	60	80	-
Glaciolacustrine silt and clay deposits	Number Of Samples	77	80	86	62	83	67	87
	Mean	82.02	387.71	117.35	2.55	1.68	917.97	628.03
	Minimum	1.80	<0.01	0.20	<0.01	0.02	198.00	2.00
	Maximum	873.00	2050.00	2360.00	30.00	29.00	7800.00	3260.00
	% exceeding the PDWO objective	8	29	10	5	58	51	-
Glaciomarine and marine silt and clay deposits	Number Of Samples	14	14	14	14	13	14	14
	Mean	69.57	46.43	62.86	1.09	0.80	528.71	328.14
	Minimum	10.00	3.00	2.00	0.10	0.05	72.00	34.00
	Maximum	250.00	150.00	160.00	5.40	5.60	900.00	574.00
	% exceeding the PDWO objective	7	0	0	0	46	57	-

Table 9. Bedrock ground water types

	Number of Samples	Ca - %	Mg - %	Na+K - %	- HCO_3 %	- SO_4+NO_3 %	- Cl %	Ca HCO_3 %	Mg HCO_3 %	Na+K HCO_3 %	Ca SO_4+NO_3 %	Mg SO_4+NO_3 %	Na+K SO_4+NO_3 %	Na+K Cl %	No Dominant Water Type %
Precambrian	3	-	-	-	33.3	-	-	66.7	-	-	-	-	-	-	-
Nepcan-March-Oxford	28	-	-	-	46.4	-	3.6	35.7	3.6	3.6	3.6	-	-	-	3.6
Rockcliffe	1	-	-	-	100.0	-	-	-	-	-	-	-	-	-	-
Ottawa Group	32	-	-	3.1	31.3	-	-	40.6	-	15.6	-	-	-	9.4	-
Simcoe Group	34	2.9	-	2.9	20.6	-	2.9	35.3	-	14.7	-	-	11.8	2.9	5.9
Billings-Carlsbad-Queenston	10	-	-	10.0	20.0	-	-	10.0	-	20.0	-	-	-	30.0	10.0
Blue Mountain-Georgian Bay	12	8.3	8.3	-	33.3	-	-	8.3	-	16.7	-	-	-	25.0	-
Queenston(central Ontario)	10	10.0	-	10.0	-	-	-	30.0	-	-	20.0	-	-	10.0	20.0
Clinton-Cataract Groups	3	-	-	-	33.3	-	-	66.7	-	-	-	-	-	-	
Amabel	69	-	-	-	10.1	-	-	78.3	-	-	8.7	-	-	-	2.9
Guelph	43	2.3	-	4.7	25.6	7.0	-	37.2	-	-	16.3	-	-	-	7.0
Salina	55	1.8	-	-	5.5	7.3	-	23.6	-	-	60.0	-	-	-	1.8
Bass Island	12	8.3	-	-	8.3	-	-	33.3	-	8.3	41.7	-	-	-	-
Bois Blanc	17	5.9	-	-	29.4	11.8	-	23.5	5.9	-	23.5	-	-	-	-
Detroit River Group	40	5.0	-	-	22.5	5.0	-	42.5	10.0	2.5	2.5	10.0	-	-	-
Dundee	27	3.7	3.7	3.7	37.0	7.4	-	11.1	3.7	14.8	3.7	-	-	3.7	7.4
Hamilton Group	3	-	-	-	-	-	-	33.3	-	33.3	-	-	-	33.3	-
Kettle Point	6	-	-	-	-	-	-	16.7	-	50.0	-	-	-	33.3	-

Table 10. General characteristics of natural ground water quality encountered in bedrock and overburden wells in southern Ontario by various parameters.

Hydrogeologic Unit: Precambrian

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	6	40.5	16.0	123.0	0.0	Excellent
Total Iron	8	7.3	<0.05	57.0	43.0	Low
Chloride	8	53.8	5.8	149.0	0.0	Excellent
Sulphate	4	189.1	9.8	635.0	25.0	Good
Total Hardness (as CaCO3)	8	250.0	112.0	550.0	N/A	Moderately hard-very hard
Total Dissolved Solids	3	412.3	261.0	514.0	0.0	Excellent

Hydrogeologic Unit: Nepean-March-Oxford

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	32	21.9	<1.0	138.0	0.0	Excellent
Total Iron	33	1.3	<0.05	15.0	27.0	Good
Chloride	33	41.0	3.0	272.0	3.0	Excellent
Sulphate	28	55.7	15.0	180.0	0.0	Excellent
Total Hardness (as CaCO3)	33	320.8	92.0	870.0	N/A	Moderately hard-very hard
Total Dissolved Solids	25	468.0	268.0	1380.0	2.0	Excellent

Hydrogeologic Unit: Ottawa Group

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Total Iron	38	0.6	0.05	26.0	45.0	Low
Sodium	39	166.5	3.6	1310.0	21.0	Good
Chloride	39	173.5	4.0	1850.0	10.0	Very good
Sulphate	37	57.0	3.0	435.0	3.0	Excellent
Total Hardness (as CaCO3)	39	277.9	30.0	530.0	N/A	Soft-very hard
Total Dissolved Solids	29	732.9	276.0	2874.0	62.0	Poor

Hydrogeologic Unit: Simcoe Group

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Total Iron	38	1.4	0.01	26.0	37.0	Medium
Sodium	34	106.3	4.0	1090.0	15.0	Very good
Chloride	38	107.9	0.5	847.0	11.0	Very good
Sulphate	35	137.1	1.0	1950.0	11.0	Very good
Total Hardness (as CaCO3)	38	285.9	31.0	1040.0	N/A	Soft-very hard
Total Dissolved Solids	33	647.3	189.0	4530.0	42.0	Low

Table 10 (cont'd)

Hydrogeologic Unit: **Billings-Carlspad-Queenston (eastern Ontario)**

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	10	300.3	1.0	1090.0	50.0	Poor
Total Iron	10	2.4	0.1	19.0	33.0	Medium
Chloride	10	304.3	5.0	1142.0	30.0	Medium
Sulphate	10	25.6	3.0	70.0	0.0	Excellent
Total Hardness (as CaCO3)	10	202.3	10.0	557.0	N/A	Soft-very hard
Total Dissolved Solids	10	947.1	234.0	2874.0	70.0	Poor

Hydrogeologic Unit: **Blue Mountain-Georgian Bay**

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	12	109.0	9.0	285.0	25.0	Good
Total Iron	12	0.4	0.01	1.6	31.0	Medium
Chloride	13	137.3	2.0	441.0	15.0	Very good
Sulphate	12	31.5	2.0	130.0	0.0	Excellent
Total Hardness (as CaCO3)	13	262.7	88.0	575.0	N/A	Moderately hard-very hard
Total Dissolved Solids	7	686.0	360.0	950.0	71.0	Poor

Hydrogeologic Unit: **Queenston (central Ontario)**

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	12	88.6	1.6	270.0	8.0	Excellent
Total Iron	5	0.2	0.05	0.6	20.0	Good
Chloride	12	123.4	3.0	445.0	17.0	Very good
Sulphate	12	250.6	18.4	1220.0	33.0	Medium
Total Hardness (as CaCO3)	12	472.1	109.0	1460.0	N/A	Hard-very hard
Total Dissolved Solids	8	953.2	251.0	2580.0	62.0	Poor

Hydrogeologic Unit: **Clinton-Cataract Groups**

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	3	12.3	2.1	17.0	0.0	Excellent
Total Iron	3	0.5	0.1	5.7	67.0	Poor
Chloride	3	37.7	2.0	69.0	0.0	Excellent
Sulphate	3	43.6	26.0	65.0	0.0	Excellent
Total Hardness (as CaCO3)	3	293.7	217.0	360.0	N/A	Very hard
Total Dissolved Solids	-	-	-	-	-	-

Table 10 (cont'd)

Hydrogeologic Unit: **Amable**

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	96	15.8	2.0	92.3	0.0	Excellent
Total Iron	19	0.5	0.01	3.0	37.0	Medium
Chloride	96	27.6	0.1	182.0	0.0	Excellent
Sulphate	96	90.2	1.0	1300.0	6.0	Excellent
Total Hardness (as CaCO3)	96	348.9	183.0	1515.0	N/A	Very hard
Total Dissolved Solids	56	479.1	211.0	2270.0	21.0	Good

Hydrogeologic Unit: **Guelph**

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	46	36.5	2.0	295.0	2.0	Excellent
Total Iron	47	1.2	0.01	33.0	60.0	Poor
Chloride	48	53.5	0.2	770.0	4.0	Excellent
Sulphate	47	243.0	2.0	1600.0	23.0	Good
Total Hardness (as CaCO3)	48	469.4	73.0	1960.0	N/A	Moderately hard-very hard
Total Dissolved Solids	43	733.3	215.0	3405.0	35.0	Medium

Hydrogeologic Unit: **Salina**

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	62	68.6	2.5	391.0	11.0	Very good
Total Iron	63	1.8	0.03	7.0	68.0	Poor
Chloride	63	38.2	0.2	590.0	5.0	Excellent
Sulphate	63	975.2	4.0	2570.0	65.0	Poor
Total Hardness (as CaCO3)	63	1110.5	168.0	2860.0	N/A	Hard-very hard
Total Dissolved Solids	62	1735.6	235.0	4190.0	69.0	Poor

Hydrogeologic Unit: **Bass Island**

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	15	32.3	5.0	174.0	0.0	Excellent
Total Iron	19	1.1	0.05	13.0	47.0	Low
Chloride	19	14.6	0.2	53.0	0.0	Excellent
Sulphate	17	503.5	5.0	2197.0	35.0	Medium
Total Hardness (as CaCO3)	19	788.3	93.9	2520.0	N/A	Moderately hard-very hard
Total Dissolved Solids	15	1220.0	235.0	3840.0	47.0	Low

Table 10 (cont'd)

Hydrogeologic Unit: **Bois Blanc**

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	21	31.5	5.0	174.0	0.0	Excellent
Total Iron	23	1.1	0.05	5.3	65.0	Poor
Chloride	23	14.6	0.2	53.0	0.0	Excellent
Sulphate	22	323.3	4.0	1875.0	32.0	Medium
Total Hardness (as CaCO3)	23	599.9	162.0	1740.0	N/A	Hard-very hard
Total Dissolved Solids	21	858.4	225.0	3040.0	48.0	Low

Hydrogeologic Unit: **Detroit River Group**

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	57	73.0	1.0	2125.0	5.0	Excellent
Total Iron	76	2.1	<0.01	70.0	64.0	Poor
Chloride	77	112.2	0.2	6820.0	1.0	Excellent
Sulphate	77	282.1	0.4	3100.0	22.0	Good
Total Hardness (as CaCO3)	76	578.4	54.0	4600.0	N/A	Soft-very hard
Total Dissolved Solids	54	1185.6	166.0	13400.0	50.0	Poor

Hydrogeologic Unit: **Dundee**

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	48	123.8	8.0	1538.0	10.0	Very good
Total Iron	78	2.2	0.01	79.0	59.0	Poor
Chloride	76	174.9	1.0	2660.0	14.0	Very good
Sulphate	75	142.1	1.0	1430.0	13.0	Very good
Total Hardness (as CaCO3)	78	378.2	37.0	2230.0	N/A	Soft-very hard
Total Dissolved Solids	44	925.8	160.0	5800.0	45.0	Low

Hydrogeologic unit: **Hamilton Group**

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	4	161.3	8.0	241.0	50.0	Poor
Total Iron	11	1.6	0.05	3.4	64.0	Poor
Chloride	11	350.4	11.0	967.0	45.0	Low
Sulphate	10	31.0	1.0	85.0	10.0	Very good
Total Hardness (as CaCO3)	11	197.8	73.0	336.0	N/A	Moderately hard-very hard
Total Dissolved Solids	4	681.5	396.0	1000.0	75.0	Poor

Table 10 (cont'd)

Hydrogeologic Unit: **Kettle Point**

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	6	478.7	28.0	2115.0	50.0	Poor
Total Iron	21	0.8	0.2	3.5	64.0	Poor
Chloride	22	261.8	26.0	3168.0	45.0	Low
Sulphate	14	11.4	1.0	82.0	10.0	Very good
Total Hardness (as CaCO3)	21	99.0	31.0	312.0	N/A	Soft-very hard
Total Dissolved Solids	5	1506.0	400.0	5530.0	75.0	Poor

Areas where the Catfish Creek Till outcrops at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	-	-	-	-	-	-
Total Iron	4	0.8	0.05	1.7	75.0	Poor
Chloride	4	48.5	5.0	162.0	0.0	Excellent
Sulphate	4	30.0	13.0	48.0	0.0	Excellent
Total Hardness (as CaCO3)	4	276.5	185.0	464.0	N/A	Hard-very hard
Total Dissolved Solids	-	-	-	-	-	-

Areas where the Port Stanley Till outcrops at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	60	40.2	2.0	231.0	3.0	Excellent
Total Iron	73	2.5	0.05	94.0	75.0	Poor
Chloride	77	60.1	0.1	2424.0	4.0	Excellent
Sulphate	76	35.0	<0.01	182.0	0.0	Excellent
Total Hardness (as CaCO3)	80	213.9	40.0	820.0	N/A	Soft-very hard
Total Dissolved Solids	52	366.2	130.0	1000.0	15.0	Very good

Areas where the Tavistock Till outcrops at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	15	248.8	8.0	1430.0	33.0	Medium
Total Iron	32	1.4	<0.01	9.5	66.0	Poor
Chloride	32	304.6	1.0	2328.0	4.0	Excellent
Sulphate	31	33.8	<0.01	400.0	3.0	Excellent
Total Hardness (as CaCO3)	32	233.5	50.0	470.0	N/A	Soft-very hard
Total Dissolved Solids	15	961.9	255.0	4300.0	60.0	Poor

Table 10 (cont'd)

Areas where the Mornington Till outcrops at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	5	21.8	17.0	27.0	0.0	Excellent
Total Iron	5	2.6	0.1	7.6	60.0	Poor
Chloride	5	9.8	1.0	22.0	0.0	Excellent
Sulphate	5	357.4	2.0	1400.0	20.0	good
Total Hardness (as CaCO3)	5	610.6	172.0	1570.0	N/A	Hard-very hard
Total Dissolved Solids	5	898.0	285.0	2320.0	80.0	Poor

Areas where the Elma Till outcrops at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	7	14.8	3.0	33.0	0.0	Excellent
Total Iron	8	1.2	<0.01	6.8	63.0	Poor
Chloride	8	23.4	2.0	138.0	0.0	Excellent
Sulphate	8	31.4	9.0	82.0	0.0	Excellent
Total Hardness (as CaCo3)	8	301.0	124.0	518.0	N/A	Hard-very hard
Total Dissolved Solids	7	440.3	285.0	800.0	29.0	Good

Areas where the Rannoch Till outcrops at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	4	23.3	5.0	45.0	0.0	Excellent
Total Iron	12	0.1	0.01	0.5	8.0	Excellent
Chloride	11	14.8	1.0	54.0	0.0	Excellent
Sulphate	12	34.6	3.0	125.0	0.0	Excellent
Total Hardness (as CaCO3)	12	251.4	42.0	391.0	N/A	Soft-very hard
Total Dissolved Solids	4	443.7	350.0	524.0	25.0	Good

Areas where the Newmarket Till outcrops at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	22	21.5	2.0	148.0	0.0	Excellent
Total Iron	22	0.5	0.1	1.6	45.0	Low
Chloride	23	22.6	1.0	226.0	0.0	Excellent
Sulphate	22	30.1	1.0	95.0	0.0	Excellent
Total Hardness (as CaCO3)	23	269.1	142.0	434.0	N/A	Hard-very hard
Total Dissolved Solids	22	397.7	254.0	735.0	23.0	Good

Table 10 (cont'd)

Areas where the Wentworth Till outcrops at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	10	8.3	2.8	16.0	0.0	Excellent
Total Iron	8	2.1	<0.01	5.8	75.0	Poor
Chloride	10	7.4	2.0	18.0	0.0	Excellent
Sulphate	10	64.7	9.0	195.0	0.0	Excellent
Total Hardness (as CaCO3)	10	279.8	142.0	408.0	N/A	Hard-very hard
Total Dissolved Solids	6	305.7	271.0	347.0	0.0	Excellent

Areas where the Halton Till outcrops at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	72	25.6	2.0	360.0	1.0	Excellent
Total Iron	43	0.8	0.02	8.1	47.0	Low
Chloride	73	52.9	1.0	677.0	5.0	Excellent
Sulphate	73	48.1	1.0	680.0	1.0	Excellent
Total Hardness (CaCO3)	73	335.1	136.0	1100.0	N/A	Hard-very hard
Total Dissolved Solids	51	466.5	200.0	2590.0	31.0	Medium

Areas where the Kettleby Till outcrops at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	7	19.3	5.0	32.0	0.0	Excellent
Total Iron	7	0.3	0.1	0.9	14.0	Very good
Chloride	7	36.7	9.0	69.0	0.0	Excellent
Sulphate	6	62.3	29.0	93.0	0.0	Excellent
Total Hardness (as CaCO3)	7	391.3	249.0	478.0	N/A	Very hard
Total Dissolved Solids	6	532.2	318.0	672.0	50.0	Poor

Areas where the St. Joseph Till outcrops at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	7	37.6	5.0	63.0	0.0	Excellent
Total Iron	7	0.4	0.2	0.7	57.0	Poor
Chloride	7	4.6	0.2	12.8	0.0	Excellent
Sulphate	7	47.0	8.0	150.0	0.0	Excellent
Total Hardness (as CaCO3)	7	155.6	85.0	316.0	N/A	Moderately hard-very hard
Total Dissolved Solids	7	303.3	183.0	528.0	14.0	Very good

Table 10 (cont'd)

Areas where Unit 19 outcrops at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	19	26.9	2.0	135.0	0.0	Excellent
Total Iron	19	0.7	0.02	11.0	16.0	Very good
Chloride	20	52.3	1.0	420.0	5.0	Excellent
Sulphate	20	39.7	4.0	15.0	0.0	Excellent
Total Hardness (as CaCO3)	20	333.8	160.0	740.0	N/A	Hard-very hard
Total Dissolved Solids	18	516.0	192.0	1540.0	33.0	Medium

Areas where unit 21 outcrops at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	3	18.0	4.0	39.0	0.0	Excellent
Total Iron	3	0.8	0.4	1.4	100.0	Poor
Chloride	3	2.3	1.0	3.0	0.0	Excellent
Sulphate	3	8.0	2.0	15.0	0.0	Excellent
Total Hardness (as CaCO3)	3	131.0	44.0	201.0	N/A	Soft-very hard
Total Dissolved Solids	3	191.0	146.0	235.0	0.0	Excellent

Areas where ice-contact deposits outcrop at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	55	25.4	1.6	485.0	4.0	Excellent
Total Iron	41	0.7	0.01	5.2	44.0	Low
Chloride	58	28.1	0.1	228.0	0.0	Excellent
Sulphate	58	56.9	0.1	600.0	5.0	Excellent
Total Hardness (as CaCO3)	57	314.9	99.0	880.0	N/A	Moderately hard-very hard
Total Dissolved Solids	48	411.7	66.1	1200.0	23.0	Good

Areas where outwash deposits outcrop at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	62	23.0	2.0	416.0	2.0	Excellent
Total Iron	42	0.8	0.05	9.1	33.0	Medium
Chloride	74	29.1	1.2	284.0	1.0	Excellent
Sulphate	76	105.1	2.0	1300.0	7.0	Excellent
Total Hardness (as CaCO3)	74	321.4	59.0	1490.0	N/A	Soft-very hard
Total Dissolved Solids	42	539.1	210.0	2200.0	21.0	Good

Table 10 (cont'd)

Areas where glaciolacustrine sand and gravel deposits outcrop at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	170	25.9	<0.01	403.0	2.0	Excellent
Total Iron	171	0.9	<0.01	11.0	44.0	Low
Chloride	191	37.4	1.0	549.0	8.0	Excellent
Sulphate	184	97.0	<0.01	2100.0	5.0	Excellent
Total Hardness (as CaCO3)	191	302.8	29.0	1940.0	N/A	Soft-very hard
Total Dissolved Solids	123	506.1	160.0	3890.0	27.0	Good

Areas where glaciomarine and marine sand and gravel deposits outcrop at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	5	72.8	16.0	230.0	20.0	Good
Total Iron	5	0.5	0.05	1.3	60.0	Poor
Chloride	5	75.2	24.0	112.0	0.0	Excellent
Sulphate	5	63.2	5.0	120.0	0.0	Excellent
Total Hardness (as CaCO3)	5	410.0	148.0	652.0	N/A	Hard-very hard
Total Dissolved Solids	5	680.2	277.0	908.0	80.0	Poor

Areas where glaciolacustrine silt and clay deposits outcrop at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	77	82.0	1.8	873.0	8.0	Excellent
Total Iron	83	1.7	0.02	29.0	58.0	Poor
Chloride	86	117.3	0.2	2360.0	10.0	Very good
Sulphate	80	387.7	<0.01	2050.0	29.0	Good
Total Hardness (as CaCO3)	87	628.0	2.0	3260.0	N/A	Soft-very hard
Total Dissolved Solids	67	918.0	198.0	7800.0	51.0	Poor

Areas where glaciomarine and marine silt and clay deposits outcrop at the surface

Parameter	No. of Samples	Mean mg/l	Min mg/l	Max mg/l	% PDWO Exceedence	General Water Quality
Sodium	14	69.5	10.0	250.0	7.0	Excellent
Total Iron	13	0.8	0.05	5.6	46.0	Low
Chloride	14	62.0	2.0	160.0	0.0	Excellent
Sulphate	14	46.4	3.0	150.0	0.0	Excellent
Total Hardness (as CaCO3)	14	328.1	34.0	574.0	N/A	Soft-very hard
Total Dissolved Solids	14	528.7	72.0	900.0	57.0	Poor

Table 10 (cont'd)

Percent Exceedence	Assigned General Water Quality
0.0 - 10.0	Excellent
10.0 - 20.0	Very good
20.0 - 30.0	Good
30.0 - 40.0	Medium
40.0 - 50.0	Low
> 50.0	Poor